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ANALYSIS OF SHOCKS BY NUMERICAL SOLUTION OF DUHAMEL'S INTEGRAL

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DECEMBER 1988

U.S. ARMY LABORATORY COMMAND

BALLISTIC RESEARCH LABORATORY

ABERDEEN PROVING GROUND, MARYLAND

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The Duhamel's integral computer code was developed to analytically test instrumentation and structures for survivability and reliability in gun launch environments and to assess the damage to the human ear due to non-classical pressure pulses and to determine the shock survivability of proposed structural designs. The shock spectra determined from Duhamel's integral for the test and environmental pulses forms a basis for comparison of the severity of the environment. The program has been installed on several machines, including mainframe computers, mini-computers and microcomputers in both BASIC and FORTRAN languages.

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I. INTRODUCTION

Some of the ongoing concerns of the Weapon Dynamics and Accuracy Branch (WDAB) of the Interior Ballistics Division (IBD) of the Ballistic Research Laboratory (BRL) are

(1) To realistically test instrumentation and structures for survivability and reliability in gun launch environments,

(2) To assess the damage to the human ear due to nonclassical pressure pulses such as those generated by multiple sources in confined volumes,

(3) To establish economic screening and quality assurance procedures for shock testing production items and

(4) To assess the shock survivability of proposed structural designs.

Two approaches that can be made to these problems are

(1) To empirically duplicate exactly the shock environment by duplicating the pulse shape, force amplitude and time duration and

(2) To empirically duplicate the severity of the environment by dissimilar pulses whose severity has been analytically determined to be relatively the same in the frequency response regime of the test item.

The latter method has been used successfully by scientists at BRL since the late sixties for various projects. This technique is dependent on the ability to determine the shock spectra from Duhamel's integral for the test and environmental pulses, thus forming a basis for comparison of severity. The main advantage of the approach is that it permits greater latitude in test facilities and provides a means of comparing different testing systems. It also provides the designer with information concerning the severity of the environment and its effect upon the structure's components.

Justification for the method is proven by consideration of several aspects of the behavior of structures. First, all structural systems are complex oscillators and they have responses in specific frequency regimes unique to the particular systems. Therefore, tests to determine survivability need only reflect the energy and momentum existing in the frequency regimes of interest.

Secondly, the relative response of the structure is deterministic and repeatable for any given pulse shape.

Thirdly, the response of the structure can be described by two spectra: the first being the primary spectrum showing the forced vibration response during the time duration of the pulse; the second being the residual spectrum showing the free vibration response after the pulse.

II. BASIC EQUATION FOR DUHAMEL'S INTEGRAL

The spectra are obtained by calculating the response of systems with discrete frequencies using the Duhamel integral over a time period three times the pulse duration. The integral in the form used is shown in Eq. (1).

$$A_r = \left[x_0 \omega_n^2 - \frac{1}{\omega_n} \int_0^s A(t_v) \sin(\omega_n t_v)\, dt_v \right] \cos(\omega_n s)$$

$$+ \left[\dot{x}_0 \omega_n + \frac{1}{\omega_n} \int_0^s A(t_v) \cos(\omega_n t_v)\, dt_v \right] \sin(\omega_n s) \tag{1}$$

where A_r = response acceleration

x_0 = initial displacement of the system

$\dot{x}_0$ = initial velocity of the system

ω_n = natural frequency of the system

$A(t_v)$ = instantaneous acceleration of the pulse at time t_v

t_v = time of observation

s = period of the system of frequency ω_n.

A numerical approach was necessary because the parameter that describes the motion $(A(t_v))$ is generally an unknown function that is approximated by a set of ordered pairs taken from a digitized set of experimental firing data.

If we assume that the pulse starts with zero displacement and velocity, then Eq. (1) can be simplified to that shown in Eq. (2).

$$A_r = \frac{\sin(\omega_n s)}{\omega_n} \int_0^s A(t_v) \cos(\omega_n t_v)\, dt_v - \frac{\cos(\omega_n s)}{\omega_n} \int_0^s A(t_v) \sin(\omega_n t_v)\, dt_v \tag{2}$$

Since the sum of the integral equals the integral of the sum, Eq. (2) can be expanded so that we do not integrate from zero for each point of the time history. The natural frequency ω_n of the system in Eq. (3) is replaced by the damped frequency ω_δ. This damped frequency is calculated by multiplying the natural frequency by $\sqrt{1-\delta^2}$, where δ is the damping factor. The expanded Eq. (2) with the damped frequency is shown in Eq. (3).

$$A_{r_{s+1}} = \frac{1}{\omega_\delta} \left[\sin(\omega_{\delta_{i+1}}) \left\{ \int_{s_0}^{s_i} A(t_v) \cos(\omega_\delta t_v)\, dt_v + \int_{s_i}^{s_{i+1}} A(t_v) \cos(\omega_\delta t_v)\, dt_v \right\} \right.$$

$$\left. - \cos(\omega_{\delta_{i+1}}) \left\{ \int_{s_0}^{s_i} A(t_v) \sin(\omega_\delta t_v)\, dt_v + \int_{s_i}^{s_{i+1}} A(t_v) \sin(\omega_\delta t_v)\, dt_v \right\} \right] \tag{3}$$

Because it is not necessary to integrate from zero for each point of time history, Eq. (3) provides considerable savings in central processing unit (cpu) time. Hence, Eq. (3) was used in the program instead of Eq. (2). This equation produces the primary system response for a given frequency.

A damping coefficient, which takes into account the viscous loss due to velocity in the system, has been incorporated into Eq. (3). This coefficient was determined from Eq. (4).

$$Damp_p = e^{(-\delta\omega_n s)} \tag{4}$$

where $Damp_p$ = damping coefficient for primary system response

δ = damping factor

ω_n = natural frequency of the system

s = period of the system of frequency ω_n.

The residual system response is obtained analytically from Eq. (5).

$$R_t = Ar_z \cos(\omega_\delta(t - z)) + A'r_z \sin(\omega_\delta(t - z)) \tag{5}$$

where R_t = residual response acceleration at time z

Ar_z = response acceleration at time z

$A'r_z$ = response velocity at time z

t = time after pulse ends

ω_δ = damped frequency of the system

z = pulse duration.

As in the primary system response, the natural frequency in Eq. (5) has been replaced by a damped frequency. Eq. (6) shows the resulting formulation.

$$R'_t = Ar_z\, e^{(-\delta\omega_\delta(t-z))} \cos(\omega_\delta(t-z)) + \frac{A'r_z\, e^{(-\delta\omega_\delta(t-z))}}{\omega_\delta} \sin(\omega_\delta(t-z)) \tag{6}$$

Where the definitions of all variables are the same as those previously listed in Eqs. (4) and (5).

III. THE COMPUTER PROGRAM

The BRL mainframe computer during the past few years has been a Control Data Corporation (CDC) CYBER 7600(MFZ). The two front-end machines were a CYBER 750(MFA) and an 825(MFB). Two new BRL supercomputers, the CRAY XMP/48 and the CRAY 2 have been installed at the BRL site. There are various minicomputers and microcomputers within the divisions of BRL. The IBD has several Hewlett-Packard (HP) microcomputers, namely the HP9845C, the HP9836C and the HP9000. Also, within the IBD is an HP1000F minicomputer.

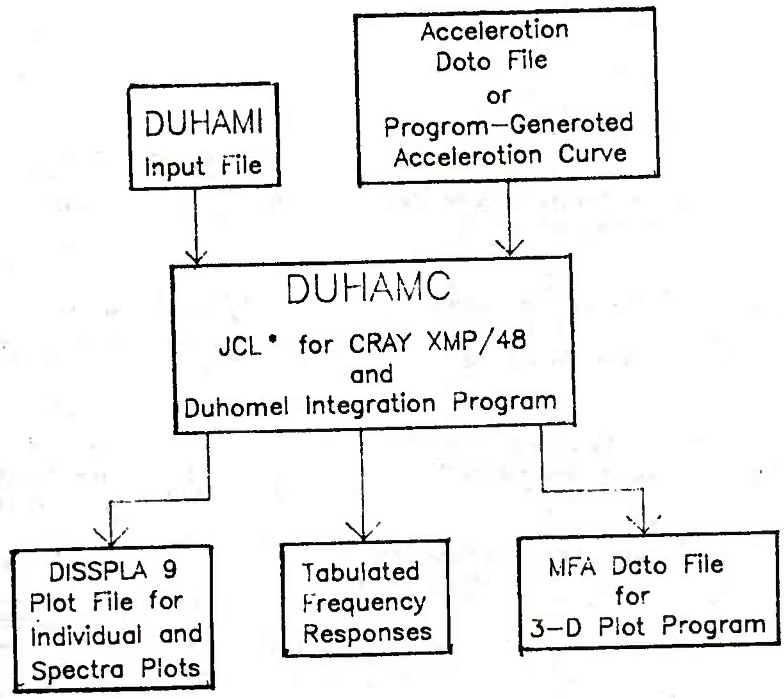
A computer program was written to numerically evaluate Duhamel's integral. The numerical integration scheme used in this program is Simpson's integration. The reciprocal of a given frequency is used as the period of the function. Additionally, the step size for Simpson's integration is less than one-eighth the period to attain reasonable accuracy using this numerical integration scheme. This step size scheme was selected so that the program would use fewer calculations in the lower frequencies.

The natural frequency ω of the system, given by $\omega = 2\pi f$ where f is the inputted frequency (in Hertz), is an integral part of the function being integrated as illustrated in Eqs. (1) through (6).

The Duhamel integral is currently coded in both FORTRAN and BASIC programming languages and has been run on the Hewlett-Packard (HP) 9845C, 9836C, CYBER 750, 825 and 7600 and the CRAY XMP/48. The code can also be used on the HP1000, HP9000 and other machines which support FORTRAN and/or BASIC. The FORTRAN version is currently being prepared, along with its job control language, to be run on the CRAY 2 machine.

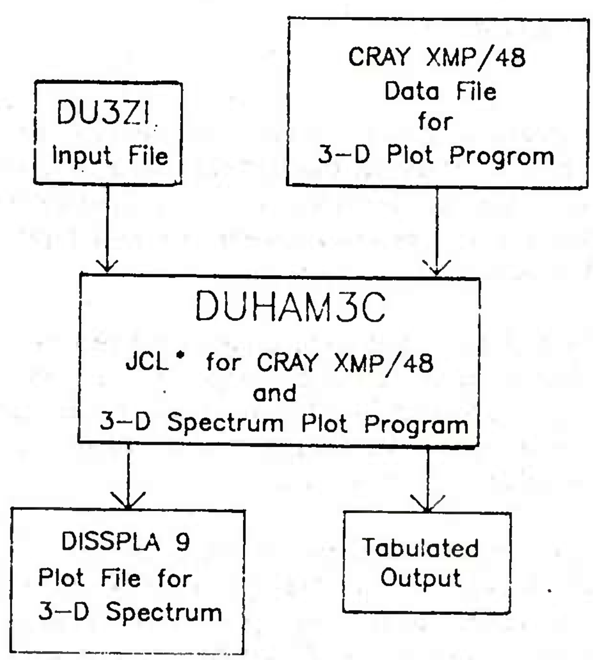
The program is fully documented and is generic for both damped and undamped systems. The FORTRAN code along with its associated job control language for CRAY XMP/48 is listed in Appendix A.

The functions and interrelationships of files run on CRAY XMP/48 are found in Figures 1 and 2. Figure 3 is a general flow diagram of the basic program.



* Job Control Language

Figure 1. CRAY XMP/48 Integration Program Sequence



* Job Control Language

Figure 2. CRAY XMP/48 3-D Plot Program Sequence

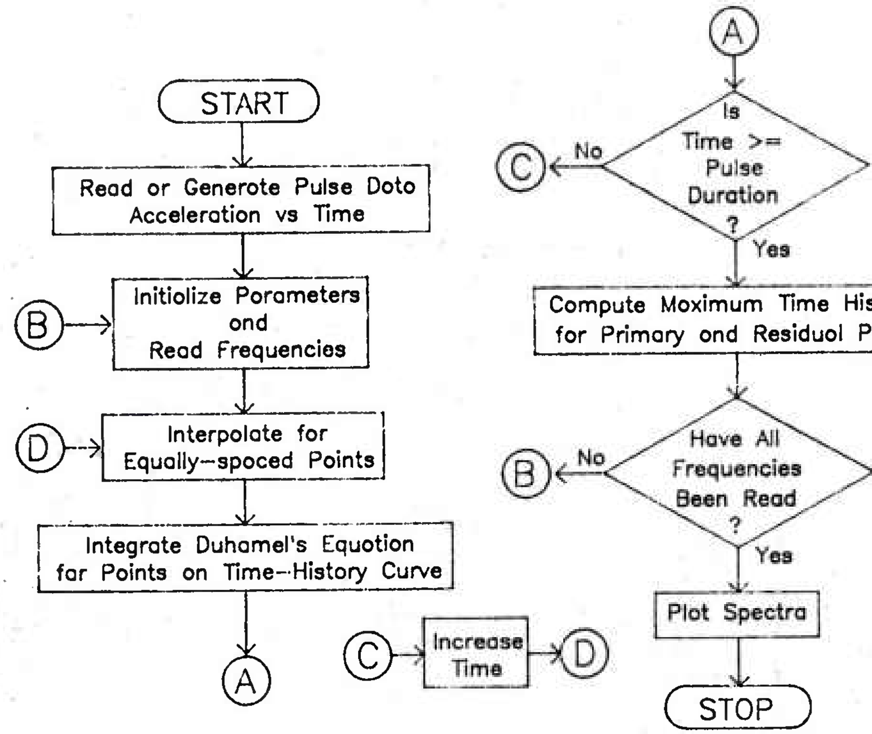


Figure 3. General Flow Diagram of the Basic Integration Program

A. Input to the Computer Program

The first step in establishing test criteria is to obtain response spectra of the shock pulse representing the environment. Thus far, the half-sine pulse, test machine pulses, interior ballistic pulses, idealized free-space blast, modified free-space blast and measured confined blast pulses have been used as representations of the environment. Figures 4 through 8 are examples of these different types of shock pulses.

These types of shock pulses are used as input to the program. Figure 4, a half-sine pulse, is an example of a code-generated curve which was generated in the Duhamel code. The idealized free-space blast and modified blast pulses, Figures 5 and 6, are curves that were generated in an auxiliary program for utilization in the Duhamel code. Figures 7 and 8 are examples of actual experimental data curves taken from firing data.

The amplitude of the input data curves is normalized to one, thus eliminating the need for dimensions. The frequency axis is normalized by multiplying the frequency by the pulse duration. This yields cycles. Depending on the program option selected, the frequency characteristics can be inputted from the keyboard, read from the data statement within the program or included as a part of the input file. The frequency range is generally between .1 and 10000 cycles. The damping characteristics are inputted from the keyboard or from a data file and range from zero to one. Figure 9 is an example of input data. Table 1 defines the input variables and lists the formats.

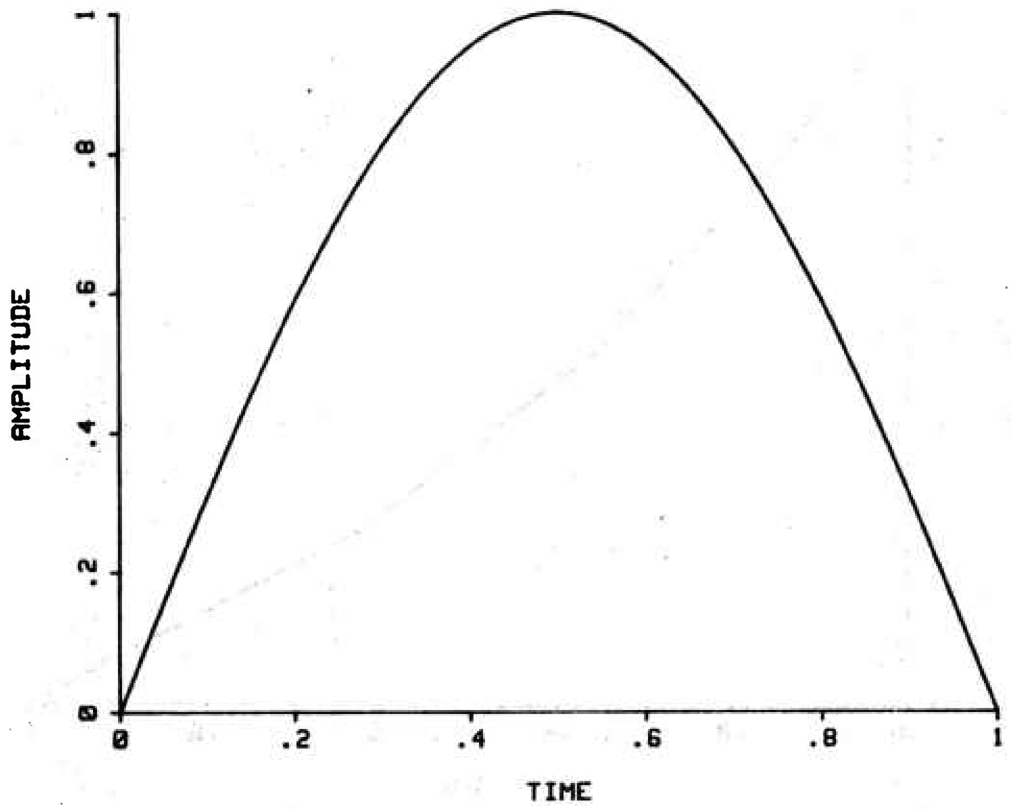


Figure 4. Program Input - Half-Sine Pulse

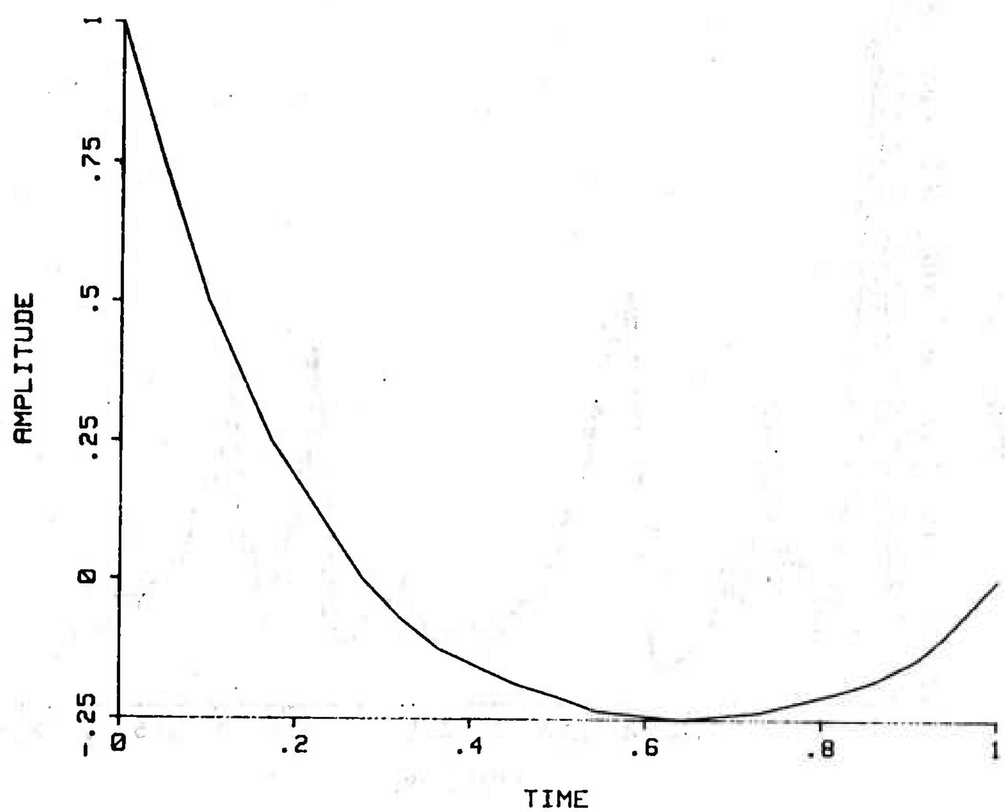


Figure 5. Program Input - Idealized Free-Space Blast Pulse

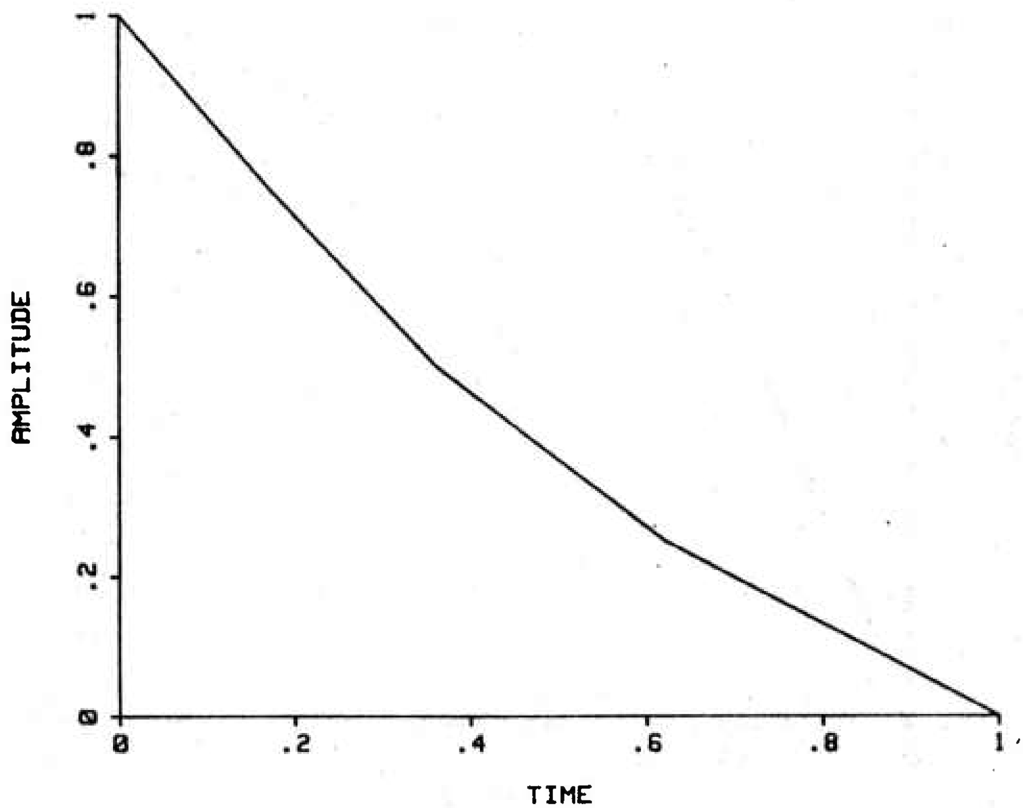


Figure 6. Program Input - Modified Blast Pulse (Positive Portion)

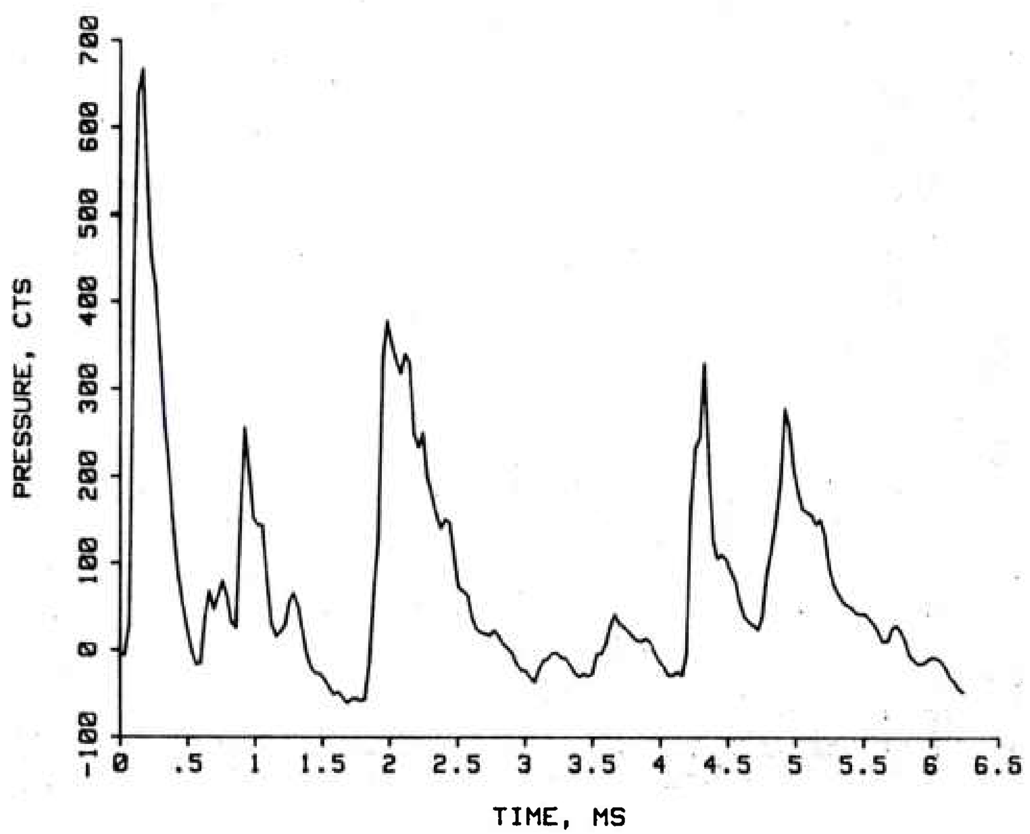


Figure 7. Program Input - Pressure Pulse Tera Socorro ID 24

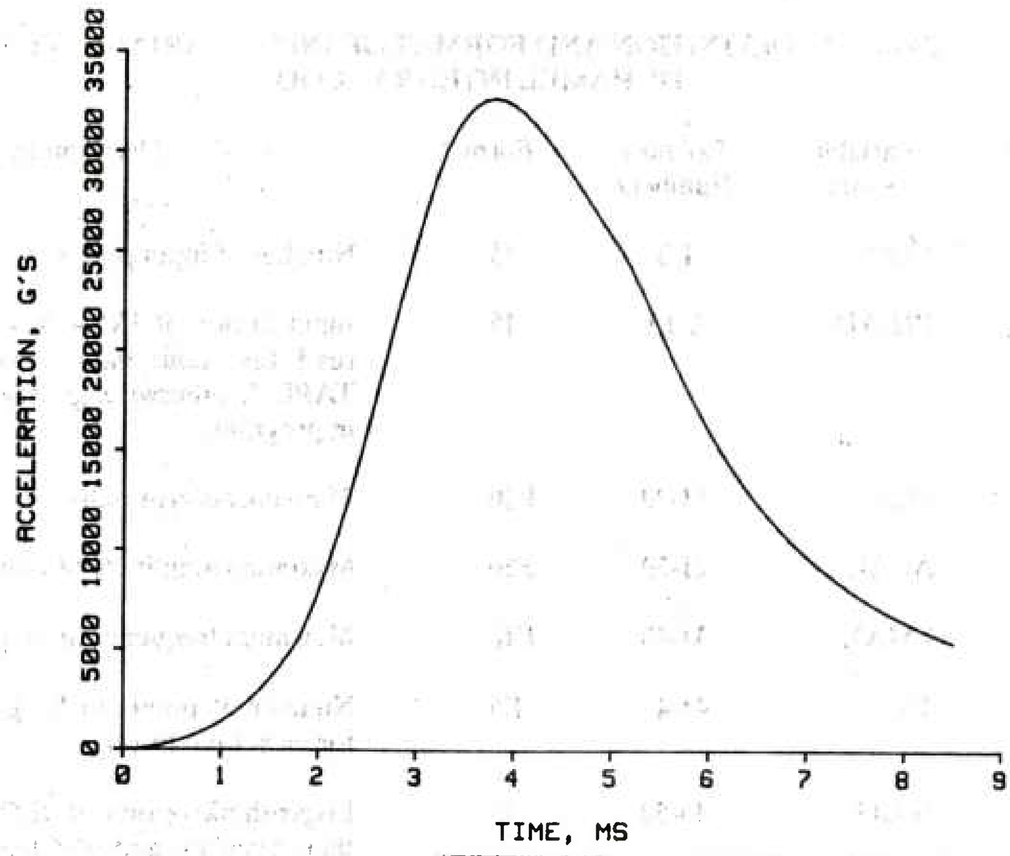


Figure 8. Program Input - Acceleration Pulse 105-mm Gun M68 M456A2

Card Number	Data
1	201 0 3.14159 1.0 10000. 100. 0 1 1 1 0
2	105MM GUN, M68 M456A2
3	ACC-TIME HISTORY OF M456A2
4	TIME, MSEC ACCELERATION, G'S
7a	.000
10	SHOCK SPECTRA M456A2
11	FRQ * PULSE DURATION STATIC ACCELERATION
12	.1 10000.0 1000. 0.0 5.0 1.

Figure 9. Sample FORTRAN Card Image Input For Duhamel Integral Code

TABLE 1. DEFINITION AND FORMAT OF INPUT VARIABLES TO DUHAMEL INTEGRAL CODE

Record Number	Variable Name	Column Numbers	Format	Description
1	NOC	1-5	I5	Number of input points.
	IREAD	6-10	I5	Input option, if IREAD = 1, then read the input data curves from TAPE 1, otherwise, generate curve in program.
	TCAL	11-20	F10	Time duration of pulse.
	ACAL	21-30	F10	Maximum amplitude of input pulse.
	FMAX	31-40	F10	Maximum frequency times pulse duration.
	TS	41-45	F5	Number of points to be generated for each time history.
	ILOG	46-50	I5	Logarithmic option, if ILOG = 1, then calculate and plot logarithmic values of frequency.
	IRES	51-55	I5	Residual option, if IRES = 1, then plot only residual spectrum.
	IFREQ	56-60	I5	Frequency option, if IFREQ = 1, then convert frequency times pulse duration to frequency.
	ISPEC	61-65	I5	Spectra option, if ISPEC = 1, then plot both primary and residual spectra.
	I3D	66-70	I5	3-D option, if I3D = 1, then plot a 3-D spectra surface.
	IPLOR	71-72	I2	Plot option, if IPLOR = 1, then plot the original input pulse, unnormalized.
	IPLNO	73-74	I2	Plot option, if IPLNO = 1, then plot the original input pulse, normalized.

TABLE 1. DEFINITION AND FORMAT OF INPUT VARIABLES TO DUHAMEL INTEGRAL CODE(cont.)

Record Number	Variable Name	Column Numbers	Format	Description
2	PGTIT	1-80	10A8	Page title to be printed on tabulated output.
3	TIT4	1-80	10A8	Plot title for unnormalized input pulse.
4	LXNAME	1-24	3A8	Label for x axis for plot of unnormalized input pulse.
	LYNAME	25-48	3A8	Label for y axis for plot of unnormalized input pulse.
5	TIT4	1-80	10A8	Plot title for normalized pulse.
6	LXNAME	1-24	3A8	Label for x axis for plot of normalized input pulse.
	LYNAME	25-48	3A8	Label for y axis for plot of normalized input pulse.
7	FT	1-10	F10	Frequency times pulse duration.
	DAMP	11-20	F10	Damping characteristic.
	IPLOT	21-25	I5	Plot option, if IPLOT = 1, then plot the time history of the individual frequency.
7a	DAMP	1-10	F10	If a spectra is being plotted, then the damping characteristic is the only variable on Input Card 7 that needs to be read. It only needs to be read once, not for each frequency.
8	TIT4	1-80	10A8	Plot title for plot of time history of an individual frequency.
9	LXNAME	1-24	3A8	Label for x axis for plot of time history of an individual frequency.

TABLE 1. DEFINITION AND FORMAT OF INPUT VARIABLES TO DUHAMEL INTEGRAL CODE(cont.)

Record Number	Variable Name	Column Numbers	Format	Description
9	LYNAME	25-48	3A8	Label for y axis for plot of time history of an individual frequency.
10	TIT4	1-80	10A8	Plot title for plot of residual and/or primary spectra.
11	LXNAME	1-24	3A8	Label for x axis for plot of residual and/or primary spectra.
	LYNAME	25-48	3A8	Label for y axis for plot of residual and/or primary spectra.
12	XORIG	1-10	E10.3	Minimum x-scale value for plot of residual and/or primary spectra.
	XMAX	11-20	E10.3	Maximum x-scale value for plot of residual and/or primary spectra.
	XSTP	21-30	E10.3	Data units per x-scale plot inch for plot of residual and/or primary spectra.
	YORIG	31-40	E10.3	Minimum y-scale value for plot of residual and/or primary spectra.
	YMAX	41-50	E10.3	Maximum y-scale value for plot of residual and/or primary spectra.
	YSTP	51-60	E10.3	Data units per y-scale plot inch for plot of residual and/or primary spectra.

B. Output From the Computer Program

Two spectra are obtained as output from the Duhamel code.

The primary spectrum which is the maximum positive or negative relative acceleration achieved during the pulse.

The residual spectrum which is the maximum positive or negative relative acceleration achieved after the pulse.

Both spectra are plotted versus frequency.

The tabulated output of the Duhamel code includes the input in its original form, the input in its normalized form and the individual responses for the selected frequencies.

The plotted output is a choice of any or all of the following:

(a) the input curve in original form,
(b) the input curve in normalized form,
(c) individual frequency response,
(d) a spectra of the primary and residual system responses to the given frequencies, and/or
(e) a three-dimensional mapping of the primary and residual system responses showing relative acceleration, time and frequencies.

C. Plot Routines

On the Hewlett-Packard machines, there is a separate plot routine for each of the plot options. The data are stored on disc and then read in by the selected plot program. In the case of the 3-D option, on all of the machines, the data must be stored for each system response individually. The data are then read by the 3-D routine, geometrically rotated and subsequently plotted. The rotation is done to provide an optimum view of each of the individual system responses. The FORTRAN code for the 3-D plot and the associated job control language for the CRAY XMP/48 are listed in Appendix B. Figure 10 is an example of actual input data while Table 2 provides a listing, including descriptions and formats, of the input variables for the 3-D spectra plot.

On the Hewlett-Packard machines, the HP graphics routines are used, while on the CRAY XMP/48, the graphics are done using the commercial plotting package DISSPLA. Version 9 of DISSPLA is now resident on the CRAY XMP/48. The plots created using DISSPLA can be displayed on a terminal screen, plotted on a printer attached to an interactive terminal and/or transferred to the CALCOMP plotter at the BRL central computer site for hardcopy.

Card Number	Data
1	50 2
2	105MM GUN, M68 M456A2
3	0. 2.5 .3125 -4. 1.5 .9167

Figure 10. Sample FORTRAN Card Image Input for Duhamel 3-D Spectra Plot

Table 2. DEFINITION AND FORMAT OF INPUT VARIABLES FOR DUHAMEL 3-D SPECTRA PLOT

Record Number	Variable Name	Column Numbers	Format	Description
1	NFILES	1-5	I5	Number of response files to be plotted.
	MAXT	6-10	I5	Maximum time of response plot. 1 = Primary response only 2 = Primary and partial residual responses 3 = Primary and full residual responses
2	TIT4	1-80	10A8	Plot title
3	XORIG	1-10	E10.3	Minimum x-scale value
	XMAX	11-20	E10.3	Maximum x-scale value
	XSTP	21-30	E10.3	Data units per x-scale plot inch
	YORIG	31-40	E10.3	Minimum y-scale value
	YMAX	41-50	E10.3	Maximum y-scale value
	YSTP	51-60	E10.3	Data units per y-scale plot inch

Figures 11, 12 and 13 show the response of systems with 30 cycles normalized frequency and .05 damping to the pulses in Figures 5 through 7, respectively. Figures 11 through 13 are individual system responses versus time for a single frequency. Figure 14 is an overlay of Figures 11, 12 and 13.

Figure 15 is the response spectra of systems with .1 to 10000 cycles normalized frequencies and .05 damping applied to the half-sine pulse, Figure 6. Figures 16 through 20 are response spectra of systems with .1 to 10000 cycles normalized frequencies and no damping applied to Figures 4 through 8, respectively. Figures 11 through 14 show both primary and residual response spectra versus frequency plotted on a semi-log plot.

In actuality, these represent normalized response curves where the abscissa is frequency times pulse duration (cycles) and the ordinate is in relative acceleration (dimensionless).

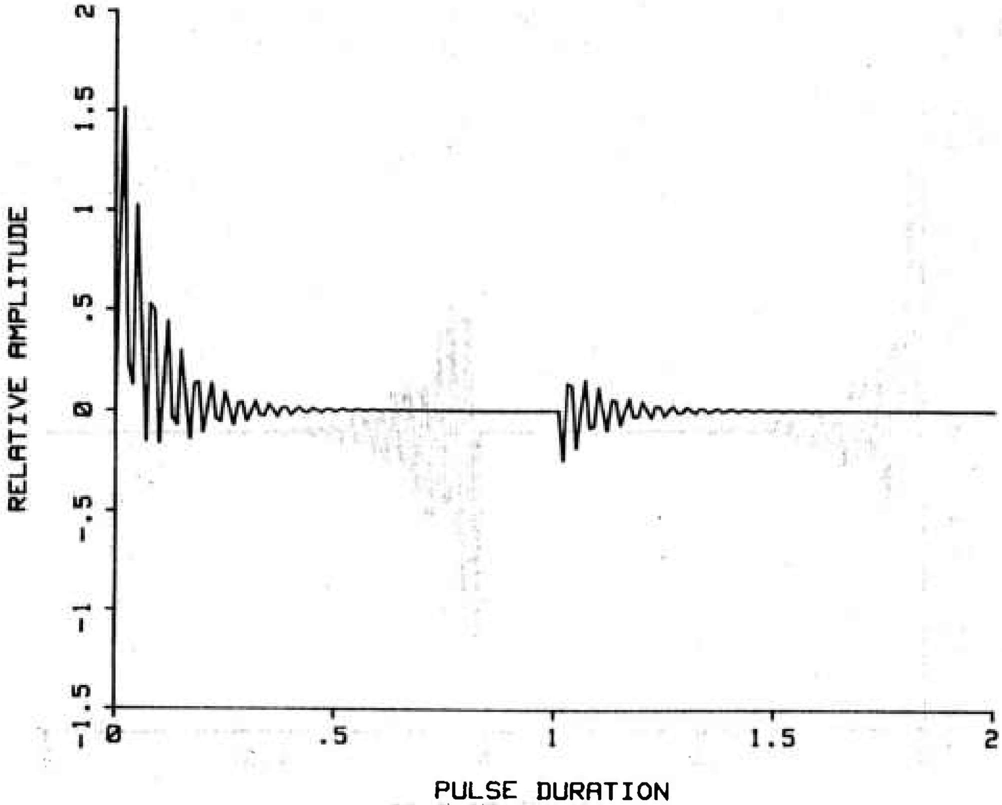


Figure 11. Response Curve (Frequency=30, Damping=.05) Idealized Free-Space Blast Pulse

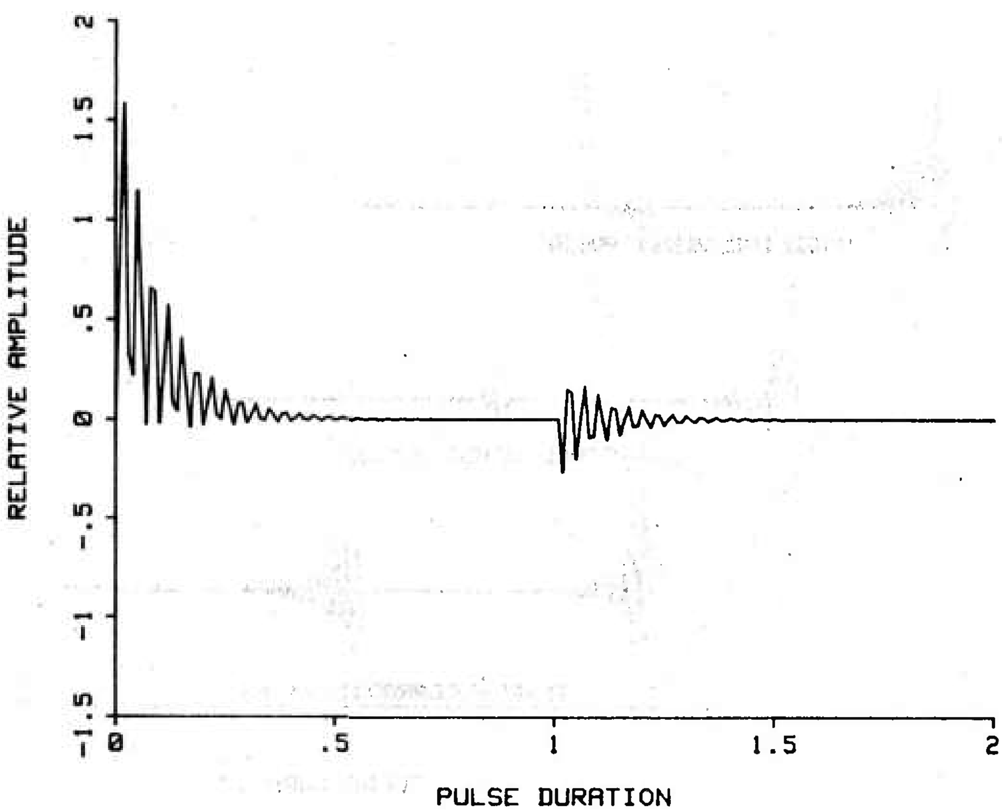


Figure 12. Response Curve (Frequency=30, Damping=.05) Modified Blast Pulse (Positive Portion)

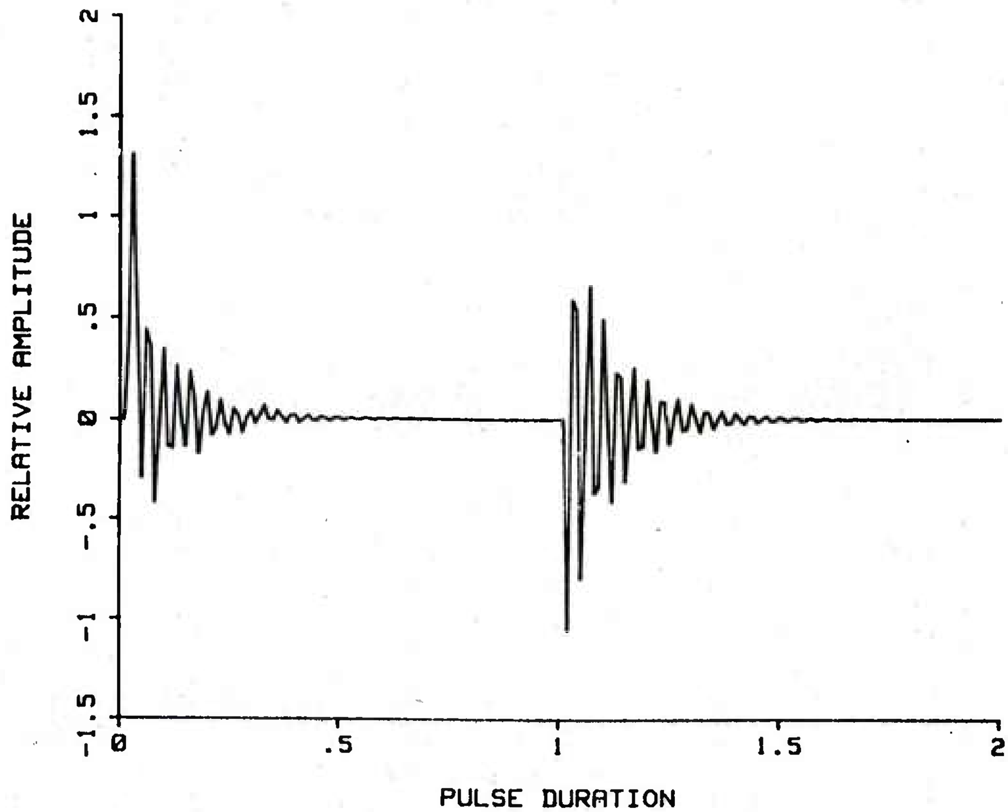


Figure 13. Response Curve (Frequency = 30, Damping = .05) Pressure Pulse Tera Socorro ID 24

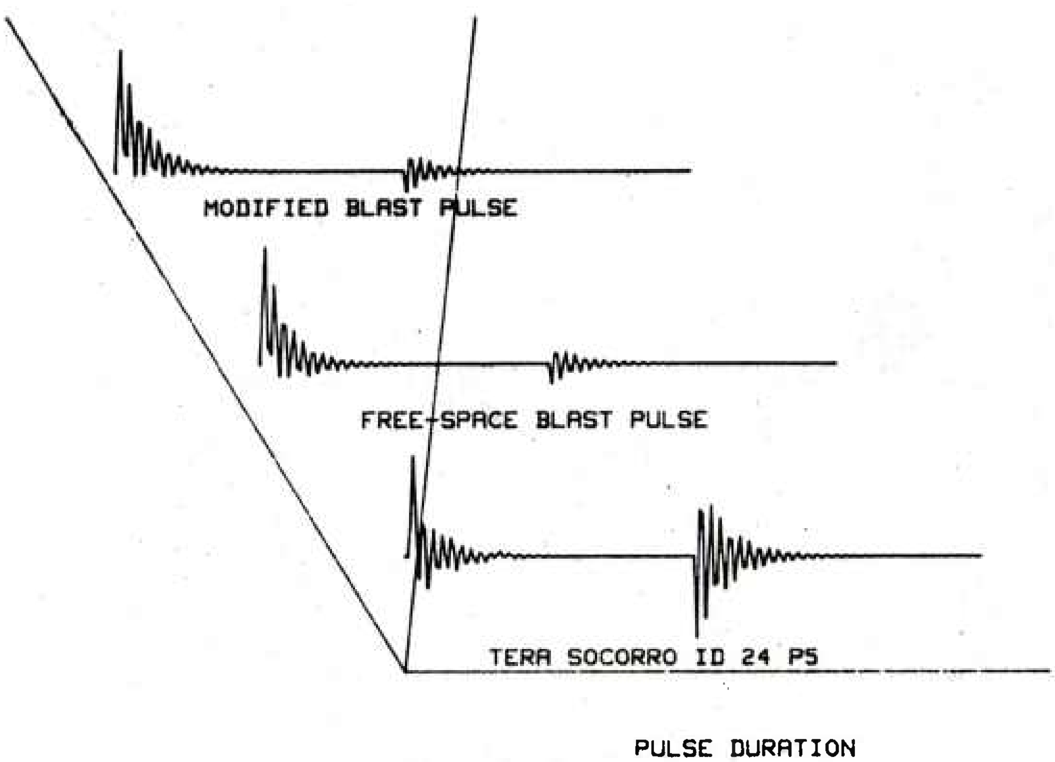


Figure 14. Comparison Response Curves (Frequency = 30, Damping = .05)

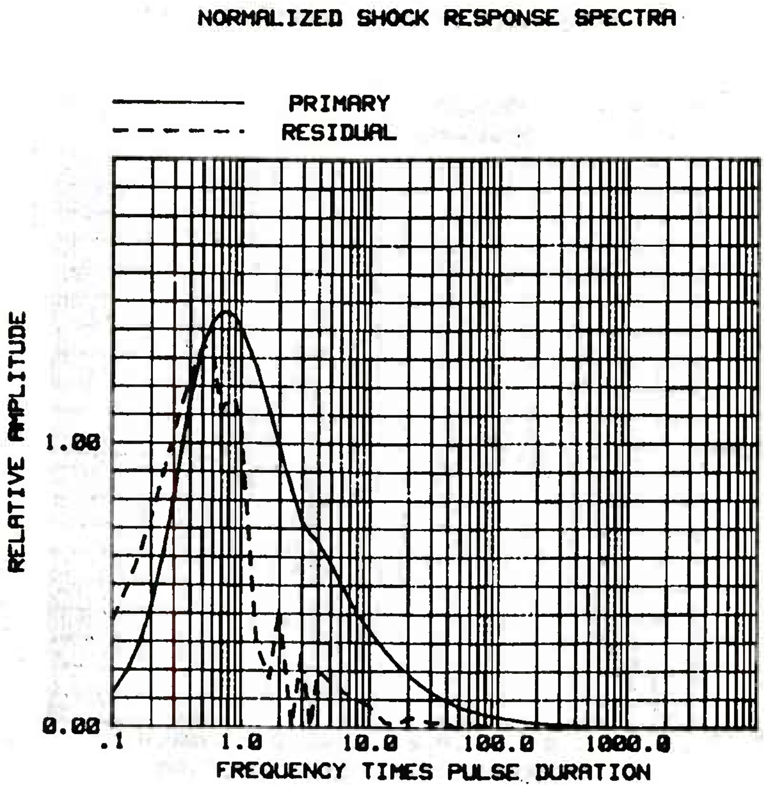


Figure 15. Normalized Shock Response Spectra - Half-Sine Pulse (Damping = .05)

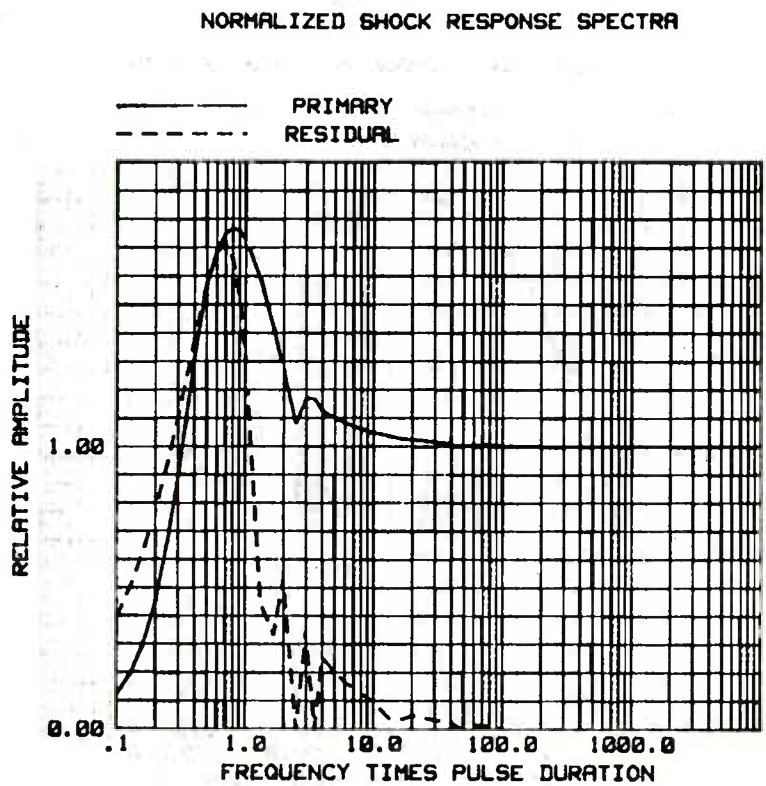


Figure 16. Normalized Shock Response Spectra - Half-Sine Pulse (Undamped)

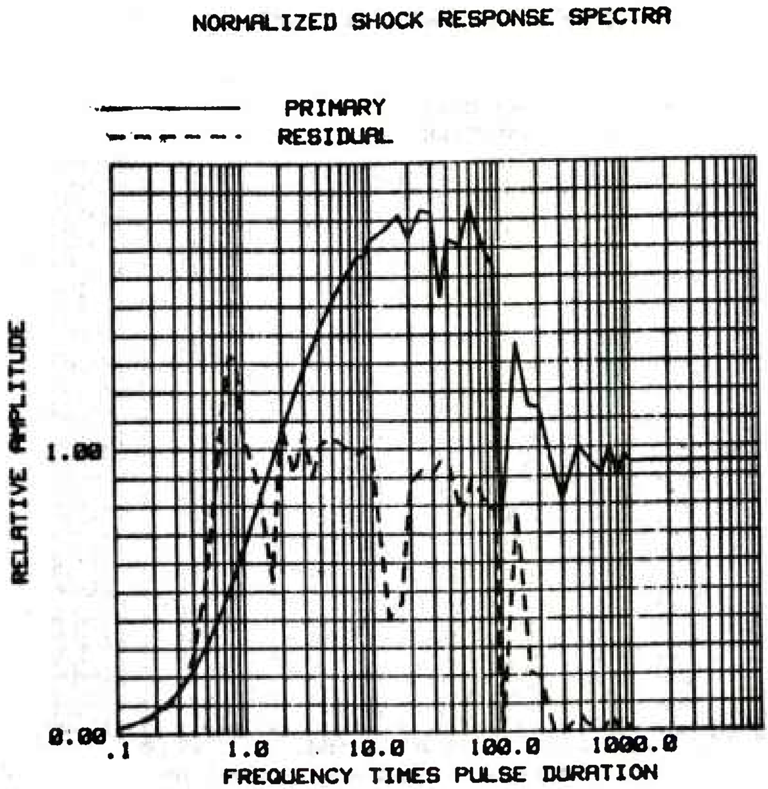


Figure 17. Normalized Shock Response Spectra - Idealized Free-Space Blast Pulse

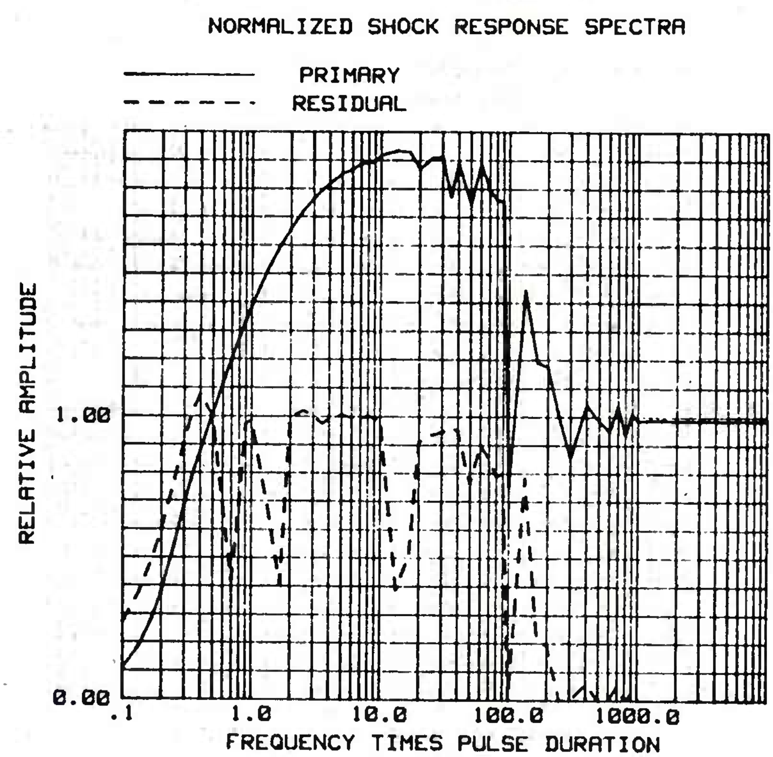


Figure 18. Normalized Shock Response Spectra - Modified Blast Pulse (Positive Portion)

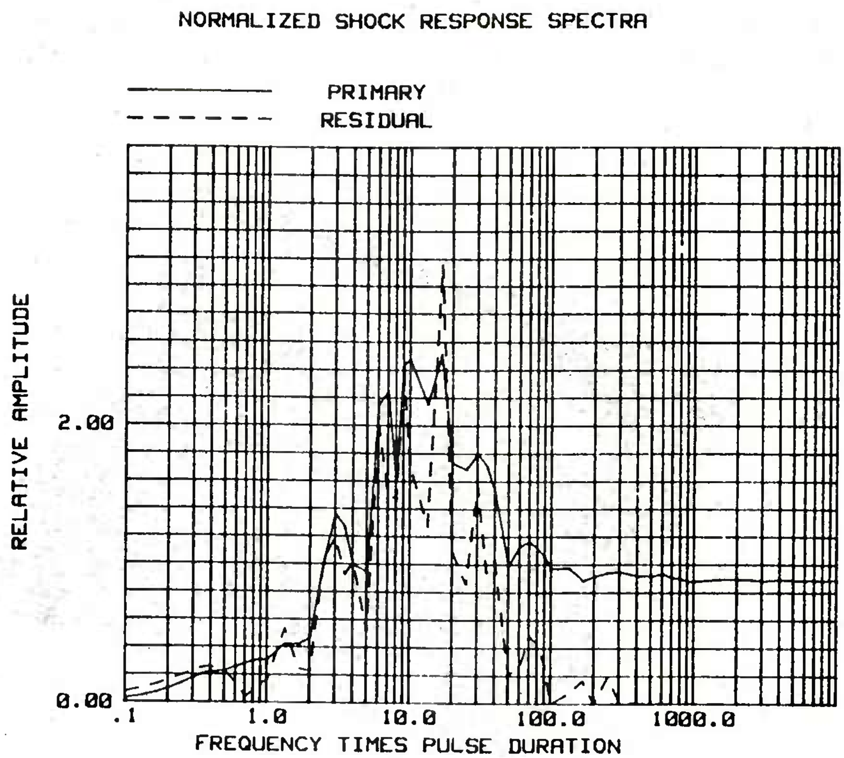


Figure 19. Normalized Shock Response Spectra - Pressure Pulse
Tera Socorro ID 24

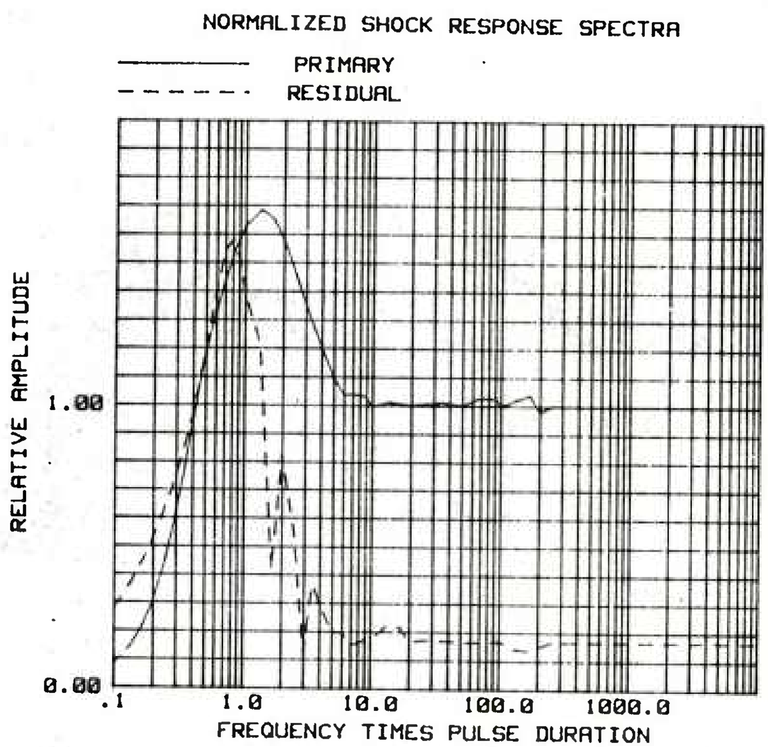


Figure 20. Normalized Shock Response Spectra - Acceleration Pulse
105-mm Gun M68 M456A2

Figures 21 through 26 are 3-D mappings of the response spectra shown in Figures 15 through 20, respectively. The three dimensions are relative acceleration, time and frequency.

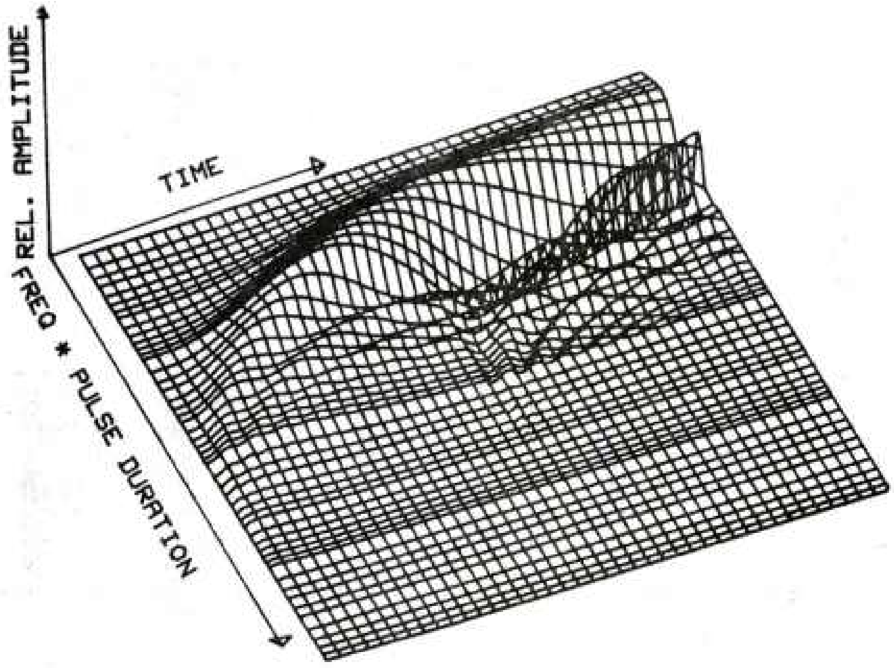


Figure 21. 3-D Shock Response - Half-Sine Pulse (Damping = .05)

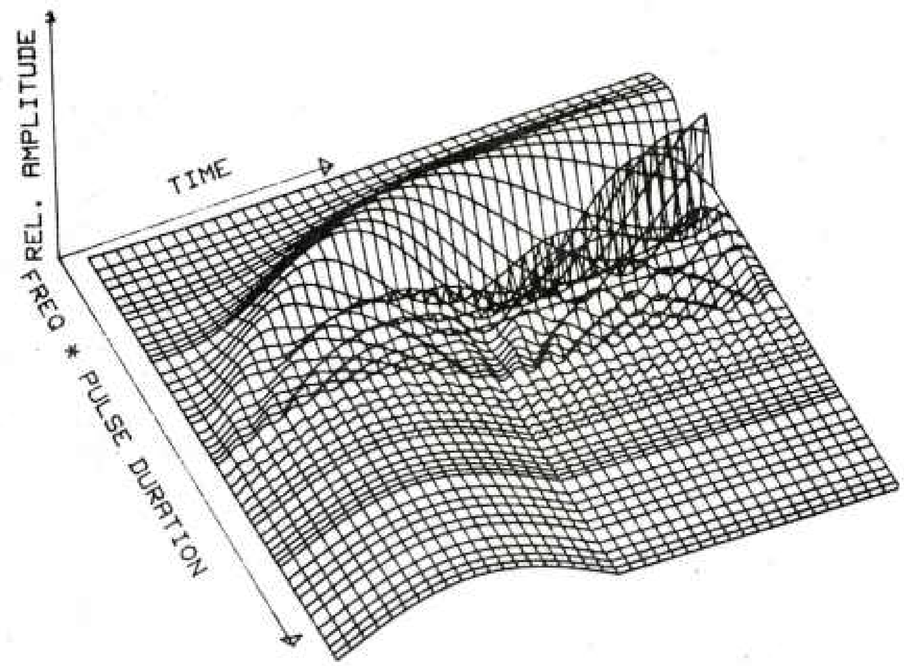


Figure 22. 3-D Shock Response - Half-Sine Pulse (Undamped)

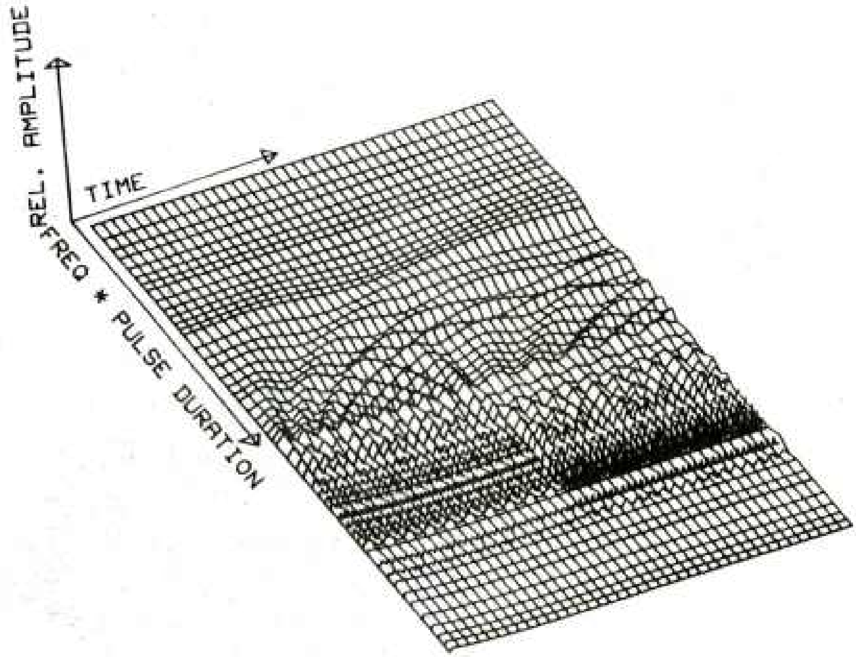


Figure 23. 3-D Shock Response - Idealized Free-Space Blast Pulse

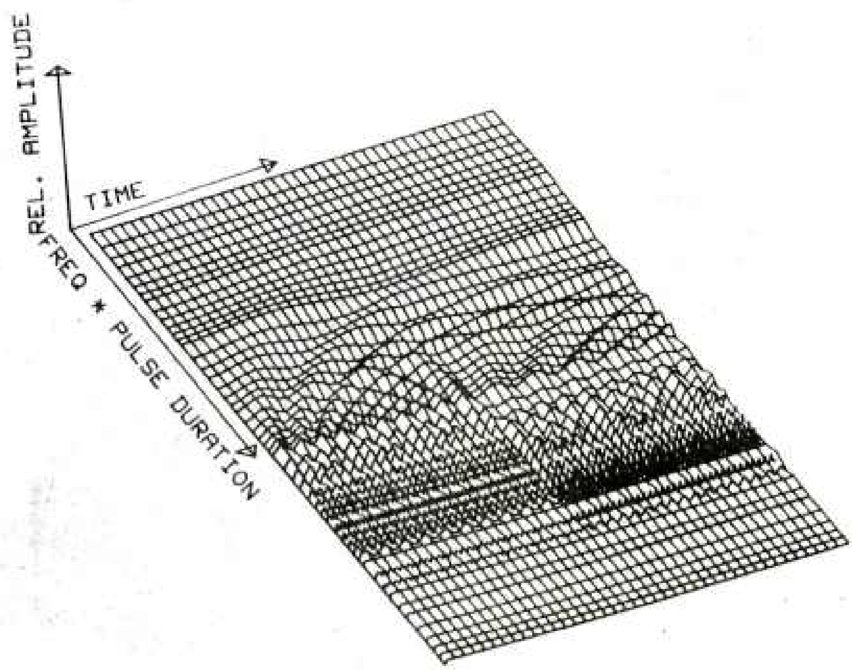


Figure 24. 3-D Shock Response - Modified Blast Pulse (Positive Portion)

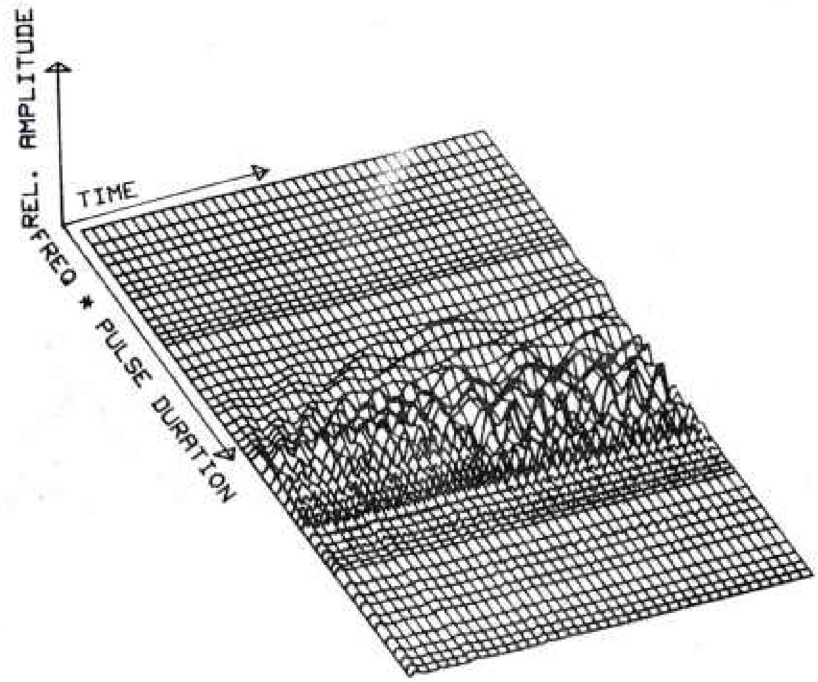


Figure 25. 3-D Shock Response - Pressure Pulse Tera Socorro ID 24

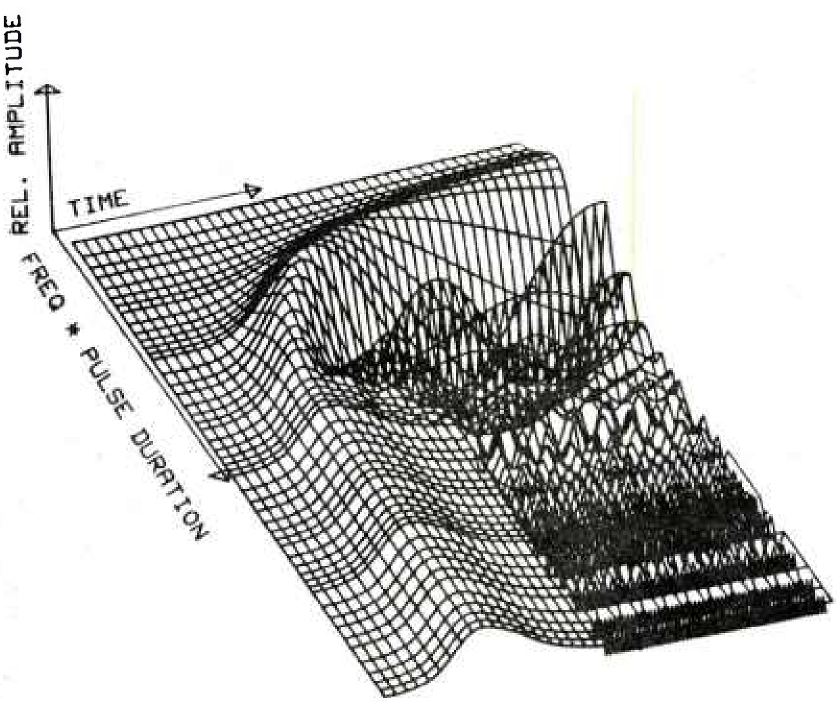


Figure 26. 3-D Shock Response - Acceleration Pulse 105-mm Gun M68 M456A2

IV. SUMMARY

The Duhamel's integral computer code was developed to analyze the transient response of test instrumentation and structures and to assess damage to the human ear caused by nonclassical pressure pulses. The code has been used to assess the relative severity of laboratory test environments with respect to gun environments. The program has been installed on a mainframe, a front-end machine and several microcomputers in BASIC and FORTRAN programming languages so as to make it more accessible to the user.

The Duhamel's integral package is now being run on the CRAY 2 supercomputer which, along with the CRAY XMP/48, has replaced the CYBER 7600 at the BRL. This code will be incorporated into the general structural and analysis scheme of the IBD. In addition, the program will be extended to compound response descriptions which include more than one frequency and other nonlinear forms, such as hardening and softening stiffness systems.

APPENDIX A

LISTING OF FORTRAN PROGRAM TO INTEGRATE DUHAMEL'S INTEGRAL ALONG WITH ASSOCIATED JOB CONTROL LANGUAGE FOR CRAY XMP/48

APPENDIX A

LISTING OF FORTRAN PROGRAMS TO INTEGRATE DUHAMEL'S INTEGRAL ALONG WITH ASSOCIATED JOB CONTROL LANGUAGE FOR CRAY XMP/48

I. Job Control Language for CRAY XMP/48

JOB,JN=*jobname*,T=150,MFL=350000.
ACCOUNT,AC=*accountnumber*,US=*username*,UPW=*userpassword.*
ACCESS,DN=DISLIB,PDN=DISLIB,ID=DISSPLA,OWN=SYSTEM.
ACCESS,DN=DVSD,PDN=DVSD,ID=DISSPLA,OWN=SYSTEM.
ACCESS,DN=INTLIB,PDN=INTLIB,ID=DISSPLA,OWN=SYSTEM.
FETCH,DN=*infile*,TEXT='CHARGE,*acctno*, *pn* .GET, *infile* =*infile* .CTASK.'.

where *infile* = name of input file which contains program options and plot titles
pn = first two letters of the account number

ASSIGN,DN=*infile* ,A=FT03.
FETCH,DN=*acfile*,TEXT='CHARGE,*acctno*, *pn* .GET,*acfile* =*acfile* .CTASK.'.

where *acfile* = name of permanent file residing on front end which contains data to be used as shock pulse

ASSIGN,DN=*acfile*,A=FT01.
ASSIGN,DN=TAPE2,A=FT02.
CFT.
SEGLDR,CMD='LIB=DISLIB,INTLIB',GO.
DISPOSE,DN=META,DC=ST,DF=BB,^
TEXT='CHARGE=*acctno*, *pn* .CTASK.REPLACE,META=*pfn* .'.

where *pfn* = name of output file in which the DISSPLA plot file is stored on the front end.

DISPOSE,DN=TAPE2,DC=ST,DF=BB,^
TEXT='CHARGE=*acctno*, *pn* .CTASK.REPLACE,TAPE2=*3dfile* .'.

where *3dfile* = name of output file that will contain data to be used in calculations for 3-D plot.

II. Listing of FORTRAN File

```
      PROGRAM SPECTRM(INPUT,OUTPUT,TAPE1,TAPE5,TAPE6=OUTPUT,
     *META,TAPE10=OUTPUT,TAPE2)
C     THIS PROGRAM NUMERICALLY INTEGRATES DUHAMEL'S INTEGRAL TO
C     OBTAIN A PRIMARY AND RESIDUAL SHOCK SPECTRA.  THE INPUT
C     CONSISTS OF A SET OF ORDERED PAIRS THAT DESCRIBE THE
C     ACCELERATION OF A SYSTEM AND A SET OF FREQUENCIES OVER
C     WHICH THE SYSTEM IS TO BE EVALUATED. THIS PROGRAM WILL ALSO
C     PLOT THE PRIMARY AND RESIDUAL SHOCK TIME HISTORY OF A GIVEN
C      FREQUENCY.
C
      DIMENSION RMAX(500),FWN(500),FR(500),MSAVE(75),XPLT(7000)
      DIMENSION PFT(200),PXP(200),PXR(200),PGTIT(10),YPLT(7000)
      DIMENSION XA(3500),XB(3500),TA(3500),TB(3500),TIT4(4)
      DIMENSION U(210),A(210),V(1040),VP(1040),DUM(1),FTR(61)
      REAL NX, NXP, MAXP, MAXR
C
      DATA PI2,PI/6.283185307,3.14159265358/
C
C     FREQUENCY INPUT DATA
C
      DATA FTR/.1,.133,.167,.2,.25,.3,.35,.4,.5,.6,.7,.8,.9,1.,1.333,
     *1.667,2.,2.5,3.,3.5,4.,5.,6.,7.,8.,9.,10.,13.333,16.667,20.,25.,
     *30.,35.,40.,50.,60.,70.,80.,90.,100.,133.333,166.667,200.,250.,
     *300.,400.,500.,600.,700.,800.,900.,1000.,2000.,3000.,4000.,5000.,
     *6000.,7000.,8000.,9000.,10000./
C
C
      CALL COMPRS
      CALL SETDEV(10,6)
C
C     ACCELERATION AND TIME ARE NORMALIZED.
C
C     NOC = NO. OF INPUT POINTS.
C     IF IREAD = 1, THEN READ INPUT DATA FROM TAPE1
C                 OTHERWISE, GENERATE DATA IN PROGRAM.
C     TCAL = TIME DURATION OF PULSE
C     ACAL = MAXIMUM ACCELERATION OF PULSE
C     FMAX = MAXIMUM FREQUENCY TIMES PULSE DURATION
C     TS = THE NUMBER OF POINTS GENERATED FOR EACH TIME HISTORY.
C     IF ILOG = 1, CALCULATE AND PLOT LOG VALUES OF FREQUENCY
C     IF IRES = 1, PLOT ONLY RESIDUAL SPECTRUM
C     IF IFREQ = 1, CONVERT FREQUENCY TIMES PULSE
C                 DURATION TO FREQUENCY.
C     IF ISPEC = 1, PLOT PRIMARY AND RESIDUAL SPECTRA
C     IF I3D = 1, PLOT A 3-D SPECTRUM SURFACE.
C     IF IPLOR = 1, PLOT THE ORIGINAL PULSE, UNNORMALIZED.
C     IF IPLNO = 1, PLOT THE ORIGINAL PULSE, NORMALIZED.
```

```
C
C       SET UP PLOT VARIABLES
C
        ISC=0
        ITYPE=0
        N4=0
        ICOLOR=0
        NCURV=1
C
C       READ AND PRINT PROGRAM CONTROL VARIABLES
C
10      READ(5,1000) NOC,IREAD,TCAL,ACAL,FMAX,TS,ILOG,IRES,
       *IFREQ,ISPEC,I3D,IPLOR,IPLNO
        IF(EOF(5).EQ.0.) GO TO 20
        CALL DONEPL
        STOP
20      WRITE(6,1000) NOC,IREAD,TCAL,ACAL,FMAX,TS,ILOG,IRES,
       *IFREQ,ISPEC,I3D,IPLOR,IPLNO
C
C       READ IN TITLE AND SET UP OTHER PLOT VARIABLES
C
        READ(5,1100) PGTIT
        WRITE(6,1200) PGTIT
        IF(IFREQ.EQ.1) FMAX=FMAX/TCAL
C
C       DO-LOOP TO READ AND NORMALIZE ORDERED PAIRS (U,A)
C
        IF(IREAD.NE.1) GO TO 30
        READ(1,1600) (U(I),A(I),I=1,NOC)
        GO TO 50
30      TIME=0.
        DO 40 I=1,NOC
        ACC=SIN(TIME)
        U(I)=TIME
        A(I)=ACC
        TIME=TIME+PI/(NOC-1)
40      CONTINUE
50      WRITE(6,1300)
        WRITE(6,1400)
        WRITE(6,1500) (U(I),A(I),I=1,NOC)
C
C       PLOT ORIGINAL INPUT PULSE
C
        IF(IPLOR.NE.1) GO TO 60
        READ(5,1100) TIT4
        LST=1
        LSP=NOC
        CALL DATA4(NCURV,U,A,DUM,NOC,ISC,ITYPE,LST,LSP,TIT4,
       *ICOLOR)
        TIME=0.
```

```
C
C        NORMALIZE INPUT PULSE
C
60       DO 70 I=1,NOC
         U(I)=U(I)/TCAL
         A(I)=A(I)/ACAL
         UMAX=U(I)
70       CONTINUE
C
C        PRINT NORMALIZED ACCELERATION PULSE
C
         WRITE(6,1700)
         WRITE(6,1300)
         WRITE(6,1500) (U(I),A(I),I=1,NOC)
C
C        PLOT PULSE CURVE
C
         IF(IPLNO.NE.1) GO TO 80
         READ(5,1100) TIT4
         LST=1
         LSP=NOC
         NCURV=1
         CALL DATA4(NCURV,U,A,DUM,NOC,ISC,ITYPE,LST,LSP,TIT4,
        *ICOLOR)
C
C        TIME AND ACCELERATION MUST START AT 0.
C
80       A(1)=0.
         U(1)=0.
C
C        S = RANGE OVER WHICH DUHAMEL'S INTEGRAL IS INTEGRATED
C        TO OBTAIN A POINT OF TIME HISTORY FOR PRIMARY SHOCK
C        SPECTRUM. PRIMARY SHOCK SPECTRUM IS GENERATED AS XA VS S.
C
         S=0
C
C        T IS USED TO GENERATE EQUALLY SPACED POINTS FOR
C        SIMPSON'S INTEGRATION
C
         T=0
C
C        DS DETERMINES THE NO. OF POINTS GENERATED FOR EACH
C        TIME HISTORY.
C
         DS=(UMAX-U(1))/TS
C
C        NP = NO. OF FREQUENCIES USED
C
         NP=1
C
```

```
C          FT IS FREQUENCY TIMES THE PULSE DURATION. F IS FREQUENCY
C          AND IS EQUAL TO FT SINCE TIME HAS BEEN NORMALIZED.
C          IF IPLOT EQUALS 1, PLOT TIME HISTORY OF FREQUENCY
C
90         IF(IRES.EQ.1.OR.ISPEC.EQ.1.OR.I3D.EQ.1) GO TO 92
           READ(5,1800) FT,DAMP,IPLOT
           WRITE(6,1800) FT,DAMP,IPLOT
           GO TO 94
92         FT=FTR(NP)
           IF(NP.EQ.1) READ(5,1800) DAMP
94         F0=FT
           FT=FT*SQRT(1.-DAMP**2)
           F=FT/UMAX
C
C          X1 AND X2 ARE RUNNING VALUES OF INTEGRATION AND ARE
C          SET TO 0 WHEN A NEW FREQUENCY IS READ.
C
           X1=0.
           X2=0.
           I=1
           K=1
           L=1
           M=1
C
C          H IS STEP SIZE FOR SIMPSON'S INTEGRATION
C
           H=DS/8.
C
C          P = PERIOD OF FUNCTION.
C
           P=1./F
C
C          H MUST BE LESS THAN 1/8 THE PERIOD FOR REASONABLE
C          ACCURACY USING SIMPSON'S INTEGRATION.
C
100        IF(H.LT.(1./8.)*P) GO TO 110
           H=H/2.
           GO TO 100
110        H3=H/3.
C
C          SWS = SIN(WS) AND CWS = COS(WS).
C
           W=PI2*F
           WD=PI2*F0
120        WS=W*S
           CWS=COS(WS)
           SWS=SIN(WS)
C
C          U AND A ARE UPDATED FOR PROPER LINEAR INTERPOLATION.
C
```

```
130   IF(T.GE.U(I).AND.T.LE.U(I+1)) GO TO 150
      IF(T.LT.UMAX) GO TO 140
C
C     T IS SET TO TMAX TO CORRECT POSSIBLE ACCUMULATIVE ERRORS
C
      T=UMAX
      GO TO 150
140   I=I+1
      GO TO 130
C
C     Y IS THE LINEAR INTERPOLATION F(T). HENCE THE NEW
C     SET OF EQUALLY SPACED ORDERED PAIRS ARE (T,Y)
C
150   Y=(T-U(I))*(A(I+1)-A(I))/(U(I+1)-U(I))+A(I)
C
C     WT = 2*PI*F*T  SWT = SIN(WT).   CWT = COS(WT).
C
      WT =W*T
      SWT=SIN(WT)
      CWT=COS(WT)
C
C     THIS SECTION APPLIES SIMPSON'S INTEGRATION FORMULA TO
C     ORDERED PAIRS (T,V) AND (T,VP) AND STORES THE RESULTS
C     IN X AND XP RESPECTIVELY. V AND VP ARE PARTS OF
C     DUHAMEL'S INTEGRAL THAT ARE TO BE INTEGRATED.
C
      V(K)=Y*SWT
      VP(K)=Y*CWT
      T=T+H
      IF(T.LT.0..OR.T.GT.UMAX+H) GO TO 300
C
C     T HAS A TOLERANCE H/2 TO ASSURE THAT LAST POINT IS USED.
C
      IF(T.GT.S+H/2.) GO TO 160
      K=K+1
      GO TO 110
C
160   OD=0.
      EV=0.
      DO 170 J=2,K,2
      OD=OD+V(J)
170   EV=EV+V(J+1)
      EV=EV-V(K)
      X=H3*(V(1)+V(K)+4.*OD+2.*EV)
      OD=0.
      EV=0.
      DO 180 J=2,K,2
      OD=OD+VP(J)
180   EV=EV+VP(J+1)
      EV=EV-VP(K)
```

```
      XP=H3*(VP(1)+VP*(K)+4.*OD+2.*EV)
C
C     X1 AND X2 SUM TERMS SO THAT WE ARE INTEGRATING OVER
C     THE RANGE 0. TO S.
C
      X1=X1+X
      X2=X2+XP
C
C     NX IS THE INTEGRAL OF DUHAMEL'S EQUATION FOR THE
C     RANGE 0. TO S.
C
      NX=EXP(-DAMP*S*WD)*W*(SWS*X2-CWS*X1)
      IF (ABS(NX).LT..1E-06) NX=0
C
C     (T,NX) IS A POINT ON THE TIME HISTORY CURVE.
C
C     WHEN S .LT. UMAX THE PROGRAM INCREASES S BY DS AND
C     DECREASES T BY H. IT THEN RETURNS TO LOCATION 120
C     AND BEGINS TO INTEGRATE THE NEXT AREA.
C
      IF (S.EQ.0.) GO TO 190
      I=I-1
190   T=T-H
      IF(IRES.EQ.1) GO TO 200
C
C     TA STORES T
C
      TA(L)=T
C
C     XA STORES NX
C
      XA(L)=NX
      XPLT(M)=T
      YPLT(M)=NX
      L=L+1
      M=M+1
200   K=1
      IF ((S-UMAX).GE.-.1E-10)GO TO 210
      S=S+DS
      GO TO 120
C
C     NXP IS THE DERIVATIVE OF THE TIME HISTORY AT UMAX.
C
210   ST=W*(T-S)
      SWST=SIN(ST)
      CWST=COS(ST)
      TT=T-S
      NXP=EXP(-DAMP*WD*TT)*W*W*(X1*SWST+X2*CWST)
     * +EXP(-DAMP*WD*TT)*W*(DAMP*WD)*(-X2*SWST+X1*CWST)
C
```

```
C         XMAX IS THE MAXIMUM VALUE OF THE RESIDUAL SPECTRUM
C
          XMAX=SQRT(NX*NX+NXP*NXP/W/W)
C
          L=1
220       ST=WD*(T-S)
          SWST=SIN(ST)
          CWST=COS(ST)
          TT=T-S
C
C         (TB,XB) ARE ORDERED PAIRS FOR THE RESIDUAL TIME HISTORY
C
          XB(L)=EXP(-DAMP*WD*TT)*(NXP*SWST/WD+NX*CWST)
          TB(L)=T
          XPLT(M)=T
          YPLT(M)=XB(L)
          M=M+1
          L=L+1
          IF(T.GE.3.*UMAX) GO TO 230
          T=T+DS
          GO TO 220
230       M=M-1
          IF(IPLOT.NE.1) GO TO 240
          READ(5,1100) TIT4
C
C         PLOT TIME HISTORY OF INDIVIDUAL FREQUENCY
C
          LST=1
          LSP=M
          CALL DATA4(NCURV,XPLT,YPLT,DUM,M,ISC,ITYPE,LST,LSP,
         * TIT4,ICOLOR)
C
C         THIS SECTION FINDS MAGNITUDE OF PRIMARY TIME HISTORY
C         (MAXP) AND MAGNITUDE OF RESIDUAL TIME HISTORY (MAXR)
C
240       MAXP=XA(1)
          MAXR=XB(1)
          DO 250 I=1,L
          IF(XA(I).LE.MAXP) GO TO 250
          MAXP=XA(I)
250       CONTINUE
          DO 260 I=1,L
          IF(XB(I).LE.MAXR) GO TO 260
          MAXR=XB(I)
260       CONTINUE
C
C         THIS SECTION STORES DATA FOR 3-D PLOT
C
          MSAVE(NP)=M
          IF(NP.EQ.1.AND.I3D.EQ.1) WRITE(2)DS
```

```
      IF (I3D.EQ.1) WRITE(2) M,(XPLT(I),I=1,M),(YPLT(I),I=1,M)
C
      IF(IFREQ.EQ.1) F=(F*UMAX)/TCAL
C
C     THIS SECTION CONVERTS FREQUENCY TIMES PULSE
C     DURATION(FT) TO FREQUENCY, IF DESIRED, AND CONVERTS
C     FT TO LOG10 SCALE, IF DESIRED, AND STORES IT
C     ALONG WITH MAXR AND XMAX FOR PLOTTING.
C
      IF(IFREQ.EQ.1) FT=FT/TCAL
      IF(ILOG.NE.1) PFT(NP)=FT
      IF(ILOG.EQ.1) PFT(NP)=ALOG10(FT)
      RMAX(NP)=MAXR
      FR(NP)=F
      FWN(NP)=F0/TCAL
      PXP(NP)=MAXP
      PXR(NP)=MAXR
      NP=NP+1
C
C     AFTER THE CODE COMPUTES THE SPECTRUM FOR FMAX, IT
C     GOES TO THE PLOT SUBROUTINE. OTHERWISE, IT RESETS T,
C     I, AND S AND RETURNS TO LOCATION 90.
C
      IF(F0.GE.FMAX)  GO TO 270
      T=0
      I=1
      S=0
      GO TO 90
C
C     NP IS NO. OF FREQUENCIES USED. IT IS RESTRICTED TO
C     200 DUE TO DIMENSION STATEMENT
C
270   NP=NP-1
C
C     PLOT PRIMARY AND RESIDUAL SPECTRA
C
      IF(ISPEC.NE.1) GO TO 280
      READ(5,1100) TIT4
      ITYPE=1
      LST=1
      LSP=NP
      NCURV=2
      ISC=1
      IF(ISPEC.EQ.1)CALL DATA4(NCURV,PFT,PXP,PXR,NP,ISC,
     *ITYPE,LST,LSP,TIT4,ICOLOR)
      IF(IRES.EQ.1) NCURV=1
      IF(IRES.EQ.1) CALL DATA4(NCURV,PFT,PXR,DUM,NP,ISC,
     *ITYPE,LST,LSP,TIT4,ICOLOR)
      ITYPE=0
      ISC=0
```

```
C
C          PRINT HEADINGS AND DATA
C
280        WRITE(6,1200) PGTIT
           WRITE(6,1900)
           WRITE(6,2000)
           IF(IFREQ.EQ.1) WRITE(6,2100)
           IF(IFREQ.NE.1) WRITE(6,2200)
           WRITE(6,2500) (FR(I),PXP(I),RMAX(I),FWN(I),I=1,NP)
           WRITE(6,2300) NP
           REWIND 2
           DO 290 I=1,1000
           V(I)=0.0
           VP(I)=0.
290        CONTINUE
           GO TO 10
300        WRITE(6,2400) T
           STOP
1000       FORMAT(2I5,3F10.3,F5.0,5I5,3I2)
1100       FORMAT(10A8)
1200       FORMAT(1H1,10A8,/)
1300       FORMAT(1H0,4(6X,'TIME',7X,'ACCELERATION',1X))
1400       FORMAT(1H ,4(6X,4HMSEC,11X,3HG'S,6X)/)
1500       FORMAT(8(1X,F14.5))
1600       FORMAT(8F10.3)
1700       FORMAT(1H1,'NORMALIZED INPUT DATA'/)
1800       FORMAT(2F10.3,I5)
1900       FORMAT('   PRIMARY AND RESIDUAL SPECTRA OF
          *ACCELERATION PULSE',//)
2000       FORMAT('    FREQUENCY',5X,'    RELATIVE
          *   ACCELERATION ACTUAL')
2100       FORMAT('       KHZ',13X,'PRIMARY    RESIDUAL
          *FREQUENCY')
2200       FORMAT(' X PULSE DURATION',5X,' PRIMARY
          *   RESIDUAL FREQUENCY')
2300       FORMAT('0NFILES = ',I5)
2400       FORMAT('0T<0 OR >  UMAX+H, T=',F10.3)
2500       FORMAT(F12.3,5X,3F12.5)
           END
C
C
C
           SUBROUTINE DATA4(NCURV,Z1,Z2,Z3,NPLT,ISC,ITYPE,LST,
          *LSP,TITLE,ICOLOR)
C
C          THIS SUBROUTINE SETS UP DATA AND LABELS FOR PLOT
C
           DIMENSION Z1(NPLT),Z2(NPLT),X(1000),Y1(1000),DUM(1),
          *Y2(1000),Z3(NPLT),LXNAME(3),LYNAME(3),TITLE(4)
           DUM(1)=1.E100
```

```
C
C         STORE DATA TO BE PLOTTED IN APPROPRIATE ARRAYS AND
C         COUNT DATA POINTS
C
          J=0
          DO 100 L=LST,LSP
          J=J+1
          X(J)=Z1(L)
          Y1(J)=Z2(L)
          Y2(J)=Z3(L)
100       CONTINUE
          IF(NCURV.LT.2) Y2(1)=DUM(1)
C
C         PRINT PLOT LIMITS
C
          WRITE(6,2) LST,LSP,X(1),X(J)
C
C         READ AND PRINT PLOT LABELS
C
          READ(5,3) LXNAME,LYNAME
          WRITE(6,3) LXNAME,LYNAME
C
C         CALL PLOT SUBROUTINE
C
          CALL DISS4(X,Y1,Y2,J,TITLE,ISC,ITYPE,LXNAME,LYNAME,
         *ICOLOR)
          RETURN
1         FORMAT(2F10.0)
2         FORMAT(' PLOT LIMITS - ',2I5,2F10.4)
3         FORMAT(10A8)
          END
C
C
          SUBROUTINE DISS4(X,Y1,Y2,NPT,TITLE,ISC,ITYPE,LXNAME,
         *LYNAME,ICOLOR)
C
C         THIS SUBROUTINE CREATES A DISSPLA 9 PLOT FILE
C
C
C         ISC=0 SELF-SCALE
C            =1 READ IN XORIG, XMAX, XSTP, YORIG, YMAX, YSTP
C
C         ITYPE=0 NORMAL PLOT
C              =1 X-LOG AXIS
C
C         ICOLOR=0 BLACK/WHITE
C               =1 COLOR
C
          DIMENSION X(NPT),Y1(NPT),Y2(NPT),RAT(10),LXNAME(3),
         * LYNAME(3),TITLE(4)
```

```
C
C         DETERMINE PLOT SCALES
C
          IF(ISC.NE.0)GO TO 300
          XORIG=X(1)
          XSTP='SCALE'
          XMAX=X(NPT)
          YORIG=1.E100
          YSTP='SCALE'
          YMAX=-1.E100
          DO 200 I=1,NPT
          IF(Y1(I).LT.YMAX)GO TO 100
          YMAX=Y1(I)
100       IF(Y1(I).GT.YORIG)GO TO 200
          YORIG=Y1(I)
200       CONTINUE
          GO TO 400
300       READ(5,1)XORIG,XMAX,XSTP,YORIG,YMAX,YSTP
400       IF(ISC.EQ.1)WRITE(6,2)XORIG,XSTP,XMAX,YORIG,YSTP,YMAX
          IF(ISC.EQ.0)WRITE(6,2)XORIG,XMAX,YORIG,YMAX
          JJ=JJ+1
C
C         SET UP GRID
C
          CALL BASALF('STANDARD')
          CALL MIXALF('SPECIAL')
          CALL PHYSOR(1.5,1.)
          CALL PAGE(11.,8.5)
          CALL SETCLR('BLACK')
          XSIZE=8.0
          YSIZE=6.0
          CALL AREA2D(XSIZE,YSIZE)
C
C          LABEL PLOTS
C
          CALL HEIGHT(.25)
          CALL HEADIN(TITLE,32,1.1,1)
          CALL XNAME(LXNAME,24)
          CALL YNAME(LYNAME,24)
C
C         SET PLOT SCALES FOR LOG PLOT
C
          IF(ITYPE.NE.1) GO TO 500
          ICY=ALOG10(X(NPT))-ALOG10(X(1))+.5
          XCY=XSIZE/FLOAT(ICY)
          IF(ITYPE.EQ.1.AND.ISC.EQ.0)YSTP=(YMAX-YORIG)/YSIZE
          WRITE(6,3) XCY,YSTP,ICY
C
C         DRAW GRID
C
```

```
500   IF(ITYPE.EQ.0)CALL GRAF(XORIG,XSTP,XMAX,YORIG,
     *YSTP,YMAX)
      IF(ITYPE.EQ.1)CALL XLOG(XORIG,XCY,YORIG,YSTP)
      IMARK=0
      IF(ICOLOR.EQ.1)CALL SETCLR('BLUE')
C
C     PLOT DATA
C
      CALL CURVE(X,Y1,NPT,IMARK)
      IF(ICOLOR.EQ.1)CALL SETCLR('RED')
      TL=.5
      NMRK=10
      RAT(1)=2.
      RAT(2)=1.
      IF(ICOLOR.EQ.0)CALL MRSCOD(TL,NMRK,RAT)
      IF(Y2(1).NE.1.E100.AND.ITYPE.EQ.0)
     *CALL CURVE(X,Y2,NPT,IMARK)
      IF(Y2(1).NE.1.E100.AND.ITYPE.EQ.1)
     *CALL CURVE(X,Y2,NPT,IMARK)
      CALL RESET('DASH')
      CALL ENDPL(JJ)
      RETURN
1     FORMAT(6E10.3)
2     FORMAT(' PLOT SCALES - ',6E13.5)
3     FORMAT(' XCYCLE, YSTP, ICY =',2E13.5,I10)
      END
```

APPENDIX B

LISTING OF FORTRAN PROGRAM TO CREATE 3-D SHOCK RESPONSE PLOT ALONG WITH ASSOCIATED JOB CONTROL LANGUAGE FOR CRAY XMP/48

APPENDIX B

LISTING OF FORTRAN PROGRAM TO CREATE 3-D SHOCK RESPONSE PLOT ALONG WITH ASSOCIATED JOB CONTROL LANGUAGE FOR CRAY XMP/48

I. Job Control Language for CRAY XMP/48

JOB,JN=*jobname*,T=150,MFL=350000.
ACCOUNT,AC=*accountnumber*,US=*username*,UPW=*userpassword.*
ACCESS,DN=DISLIB,PDN=DISLIB,ID=DISSPLA,OWN=SYSTEM.
ACCESS,DN=DVSD,PDN=DVSD,ID=DISSPLA,OWN=SYSTEM.
ACCESS,DN=INTLIB,PDN=INTLIB,ID=DISSPLA,OWN=SYSTEM.
FETCH,DN=*3dfile*,TEXT='CHARGE,*acctno*, *pn* .GET, *3dfile* =*3dfile* .CTASK.',DF=BB.

where *3dfile* = name of input file which contains data for calculations for 3-D plot
pn = first two letters of account number

ASSIGN,DN=3dfile,A=FT01.
FETCH,DN=*infile*,TEXT='CHARGE,*acctno*, *pn* .GET, *infile* =*infile* .CTASK.'.

where *infile* = name of input file which contains program options and plot titles
pn = first two letters of the account number

ASSIGN,DN=*infile* ,A=FT05.
CFT.
SEGLDR,CMD='LIB=DISLIB,INTLIB',GO.
DISPOSE,DN=META,DC=ST,DF=BB,^
TEXT='CHARGE=*acctno* , *pn* .CTASK.REPLACE,META=*pl 3file* .'.

where *pl 3file* = name of output file in which the DISSPLA plot file for 3-D plot is stored on the front end.

II. Listing of FORTRAN File

```
      PROGRAM DUHM3D(INPUT,OUTPUT,TAPE1,TAPE5,
     * TAPE6=OUTPUT,META,TAPE10=OUTPUT,TAPE2)
C
C     THIS PROGRAM READS FREQUENCY RESPONSE DATA AND
C     CREATES A 3-D SURFACE PLOT
C
C     THIS PROGRAM USES A DATA FILE CREATED BY A
C     DUHAMEL INTEGRAL PROGRAM AS INPUT
```

```
C
      DIMENSION TX(65),TY(65),TX1(65),TY1(65)
      DIMENSION TX2(65),TY2(65),TX3(65),TY3(65),TX4(65),TY4(65)
      DIMENSION OFF(50),OFFX(50),PARRAY(1500,4),RES(1500,4),
     * T1(4,4),XPT(1500),YPT(1500),TIT4(4),XPLT(1500),YPLT(1500),
     * T2(4,4)
C
      DATA OFF/1.,1.33,1.67,2.,2.5,3.,3.5,4.,5.,6.,7.,8.,9.,10.,13.3,
     *16.7,20.,25.,30.,35.,40.,50.,60.,70.,80.,90.,100.,133.33,166.67,
     *200.,250.,300.,350.,400.,500.,600.,700.,800.,900.,1000.,1333.3,
     *1666.67,2000.,2500.,3000.,4000.,5000.,6000.,7000.,8000./
C
C     INITIALIZE DISSPLA
C
      CALL COMPRS
      CALL SETDEV(10,6)
C
      ISC=1.
      ICOLOR=1
      IEP=1
C
C     NFILES(I5) = NUMBER OF FREQUENCY RESPONSE CURVES
C     MAXT  (I5) = MAXIMUM TIME OF RESPONSE PLOT
C          MAXT = 1, PRIMARY RESPONSE CURVE
C          MAXT = 2, PRIMARY RESPONSE PLUS PARTIAL RESIDUAL
C          MAXT = 3, PRIMARY RESPONSE PLUS FULL RESIDUAL
C
      READ(5,1000) NFILES,MAXT
      NF=NFILES
C
C     DS = TIME STEP READ FROM DATA FILE
C
      READ(1) DS
      WRITE(6,5000) DS
C
C     CALCULATE NUMBER AND INTERVAL OF TIME CURVES
C     TO BE PLOTTED
C
      K=(MAXT/DS)+1
      A=MAXT
      B=AMOD(A,DS)
      IF(B.GE..0)K=K+1
      KD=K/4
      J1=4
      J=MOD(K,J1)
      IF(J.GT.0)KD=KD+1
      KS=K/100
      J1=100
      J=MOD(K,J1)
      IF(J.GT.0)KS=KS+1
```

```
      KD2=2*KD
      KD3=3*KD
      KP=0
      WRITE(6,6000) KD,KS,K
      IPSAVE=10000
C
C     READ DATA AND STORE IN SEPARATE ARRAYS TO CREATE
C     DATA CURVES AT SPECIFIC TIME INTERVALS
C
      DO 80 J=1,KD,KS
      IS=0
      DO 60 I=1,NF
      IS=IS+1
      IF(J.GT.1.AND.I.EQ.1) READ(1) DS
      READ(1) M,(XPLT(N),N=1,M),(YPLT(N),N=1,M)
      IF(I.EQ.1.AND.J.EQ.1)WRITE(6,4000) (XPLT(N),N=1,M),(YPLT(N),N=1,M)
      IF(J.EQ.1.AND.I.EQ.1) GO TO 30
10    IF((J+KD2).GT.IPSAVE) KP=1
      TX(I)=XPLT(J)
      TY(I)=YPLT(J)
      TX1(I)=XPLT(J+KD)
      TY1(I)=YPLT(J+KD)
      TX2(I)=XPLT(J+KD2+KP)
      TY2(I)=YPLT(J+KD2+KP)
      TX3(I)=XPLT(J+KD3+KP)
      TY3(I)=YPLT(J+KD3+KP)
      IF((J+KS).GT.KD.AND.J.NE.KD) GO TO 20
      GO TO 60
20    IF(I.EQ.1) IEND=1
      TX4(I)=XPLT(K)
      TY4(I)=YPLT(K)
      GO TO 60
30    K1=1
      DO 40 IP=1,M
      IF((XPLT(IP+1)-XPLT(IP)).LT..001) IPSAVE=IP
      IF(ABS(MAXT-XPLT(IP)).LT..0001) GO TO 50
      K1=K1+1
40    CONTINUE
50    K=K1
      GO TO 10
60    CONTINUE
      REWIND 1
C
C     STORE NEWLY CREATED DATA CURVES
C
      WRITE(2) IS,(TX(N),N=1,IS),(TY(N),N=1,IS)
      NFILES=NFILES+1
      WRITE(2) (TX1(N),N=1,IS),(TY1(N),N=1,IS)
      NFILES=NFILES+1
      WRITE(2) (TX2(N),N=1,IS),(TY2(N),N=1,IS)
```

```
      NFILES=NFILES+1                                                   DU3D 109
      WRITE(2) (TX3(N),N=1,IS),(TY3(N),N=1,IS)                          DU3D 110
      NFILES=NFILES+1                                                   DU3D 111
      WRITE(6,4000) (TX(N),N=1,8),(TY(N),N=1,8)                         DU3D 112
      IF (IEND.NE.1) GO TO 70                                           DU3D 113
      WRITE(2) (TX4(N),N=1,IS),(TY4(N),N=1,IS)                          DU3D 114
      NFILES=NFILES+1                                                   DU3D 115
70    WRITE(6,2000) J                                                   DU3D 116
      IF (IEND.EQ.1) WRITE(6,3000)                                      DU3D 117
80    CONTINUE                                                          DU3D 118
      REWIND 2                                                          DU3D 119
C                                                                       DU3D 120
C     GENERATE OFFSET FACTORS FOR PLOTTING                              DU3D 121
C                                                                       DU3D 122
      RMS=(ALOG10(OFF(NF))-ALOG10(OFF(1)))/(NF*.01)                     DU3D 123
      DO 90 I=1,NF                                                      DU3D 124
      OFFX(I)=(ALOG10(OFF(NF))-ALOG10(OFF(I))-NF*.01*RMS)/(-RMS)        DU3D 125
90    CONTINUE                                                          DU3D 126
C                                                                       DU3D 127
C     SET UP ARRAYS FOR CURVE ROTATION                                  DU3D 128
C                                                                       DU3D 129
      AX=1HY                                                            DU3D 130
      ANG=53                                                            DU3D 131
      CALL ROT1 (ANG,AX,T1)                                             DU3D 132
      AX=1HX                                                            DU3D 133
      ANG=67                                                            DU3D 134
      CALL ROT1 (ANG,AX,T2)                                             DU3D 135
C                                                                       DU3D 136
C     READ DATA FROM FILES                                              DU3D 137
C                                                                       DU3D 138
      IMAXC=NFILES                                                      DU3D 139
      DO 180 II=1,NFILES                                                DU3D 140
      J1=4                                                              DU3D 141
      J=MOD((II-NF),J1)                                                 DU3D 142
      MM=1                                                              DU3D 143
      IF(II.GT.NF) GO TO 100                                            DU3D 144
      IF(II.EQ.1) READ(1) DS                                            DU3D 145
      READ(1) M,(XPLT(I),I=1,M),(YPLT(I),I=1,M)                         DU3D 146
      GO TO 120                                                         DU3D 147
100   IF(J.EQ.1.AND.II.NE.NFILES)GO TO 110                              DU3D 148
      READ(2) (XPLT(I),I=1,M),(YPLT(I),I=1,M)                           DU3D 149
      GO TO 120                                                         DU3D 150
110   READ(2) M,(XPLT(I),I=1,M),(YPLT(I),I=1,M)                         DU3D 151
C                                                                       DU3D 152
C     ROTATE DATA                                                       DU3D 153
C                                                                       DU3D 154
120   DO 130 JJ=1,M                                                     DU3D 155
      PARRAY(MM,2)=YPLT(JJ)                                             DU3D 156
      PARRAY(MM,1)=XPLT(JJ)                                             DU3D 157
      PARRAY(MM,3)=0.                                                   DU3D 158
```

```
      PARRAY(MM,4)=1.
      MM=MM+1
      IF(II.GT.NF) GO TO 130
      IF(XPLT(JJ).GE.MAXT) GO TO 140
130   CONTINUE
140   MM=MM-1
      IA=MM
      IM=1500
      JM=4
      KM=4
      NM=1500
      CALL MATMPY(PARRAY,T1,RES,IA,JM,KM,IM,JM,NM)
      CALL MATMPY(RES,T2,PARRAY,IA,JM,KM,IM,JM,NM)
C
C     OFFSET DATA FOR PLOTTING
C
      DO 170 JJ=1,MM
      IF(II.LE.NF) GO TO 150
      OFFSETX=OFFX(JJ)
      OFFSET=OFF(JJ)
      IF(IEND.EQ.1.AND.II.EQ.NFILES.AND.JJ.EQ.MM)OFFSET=OFF(50)
      GO TO 160
150   OFFSETX=OFFX(II)
      OFFSET=OFF(II)
160   XPT(JJ)=PARRAY(JJ,1)+OFFSETX
      YPT(JJ)=PARRAY(JJ,2)-ALOG10(OFFSET)
170   CONTINUE
C
C     READ PLOT TITLE AND CALL PLOT ROUTINE
C
      IF(IEP.EQ.1) READ(5,7000) TIT4
      LST=1
      LSP=MM
      NPLT=1500
      CALL DATA4(XPT,YPT,NPLT,ISC,LST,LSP,TIT4,ICOLOR,IEP,IMAXC)
      IEP=IEP+1
180   CONTINUE
      CALL DONEPL
1000  FORMAT(2I5)
2000  FORMAT(' CYCLE NO. ',I5,' HAS BEEN STORED')
3000  FORMAT(' FINAL FILE HAS BEEN STORED')
4000  FORMAT(8F12.5)
5000  FORMAT('0DS= ',F30.20)
6000  FORMAT(' KD KS K ',3I10)
7000  FORMAT(10A8)
      STOP
      END

C
      SUBROUTINE ROT1(ANG,AX,T)
```

```
C
C        THIS SUBROUTINE CREATES A MATRIX FOR ROTATION OF DATA
C
C
         DIMENSION T(4,4)
C
C        CONVERT DEGREES TO RADIANS
C
         ANG=ANG*.01745329
C
C        ZEROING OUT THE T ARRAY
C
         DO 100 I=1,4
         DO 100 J=1,4
         T(I,J)=0.0
100      CONTINUE
         IF(AX.EQ.1HY) GO TO 200
         IF(AX.EQ.1HZ) GO TO 300
C
C        X-AXIS ARRAY
C
         T(2,3)=SIN(ANG)
         T(2,2)=COS(ANG)
         T(3,2)=-T(2,3)
         T(3,3)=T(2,2)
         T(1,1)=1.
         GO TO 400
C
C        Y-AXIS ARRAY
C
200      T(3,1)=SIN(ANG)
         T(1,1)=COS(ANG)
         T(1,3)=-T(3,1)
         T(3,3)=T(1,1)
         T(2,2)=1.
         GO TO 400
C
C        Z-AXIS ARRAY
C
300      T(1,3)=SIN(ANG)
         T(1,1)=COS(ANG)
         T(2,1)=-T(1,3)
         T(2,2)=T(1,1)
         T(3,3)=1.
400      RETURN
         END

C
         SUBROUTINE DATA4(Z1,Z2,NPLT,ISC,LST,LSP,TITLE,ICOLOR,
         *IEP,IMAXC)
```

```
C
C         THIS SUBROUTINE SETS UP DATA FOR PLOTTING
C         AND CREATES A 3-D DISSPLA 9 PLOT FILE
C
          DIMENSION Z1(NPLT),Z2(NPLT),X(1000),Y1(1000),TITLE(4)
C
C         ISC=0 SELF-SCALE
C             =1 READ IN XORIG, XMAX, XSTP, YORIG, YMAX, YSTP
C
C         ICOLOR=0 BLACK/WHITE
C                =1 COLOR
C
C
C         STORE DATA TO BE PLOTTED IN APPROPRIATE ARRAYS AND
C         COUNT DATA POINTS
C
          J=0
          DO 10 L=LST,LSP
          J=J+1
          X(J)=Z1(L)
          Y1(J)=Z2(L)
10        CONTINUE
C
C         PRINT PLOT LIMITS
C
          WRITE(6,3000)LST,LSP,X(1),X(J)
          NPT=J
          IF(IEP.GT.1) GO TO 60
C
C         DETERMINE PLOT SCALES
C
          IF(ISC.NE.0)GO TO 40
          XORIG=X(1)
          XSTP='SCALE'
          XMAX=X(NPT)
          YORIG=1.E100
          YSTP='SCALE'
          YMAX=-1.E100
          DO 30 I=1,NPT
          IF(Y1(I).LT.YMAX)GO TO 20
          YMAX=Y1(I)
20        IF(Y1(I).GT.YORIG)GO TO 30
          YORIG=Y1(I)
30        CONTINUE
          GO TO 50
40        READ(5,1000)XORIG,XMAX,XSTP,YORIG,YMAX,YSTP
50        IF(ISC.EQ.1)WRITE(6,2000)XORIG,XSTP,XMAX,YORIG,YSTP,YMAX
          IF(ISC.EQ.0)WRITE(6,2000)XORIG,XMAX,YORIG,YMAX
          JJ=JJ+1
C
```

```
C          SET UP PLOTTING AREA                                   DAT4  53
C                                                                 DAT4  54
           CALL PHYSOR(1.5,1.)                                    DAT4  55
           CALL NOBRDR                                            DAT4  56
           CALL PAGE(11.,8.5)                                     DAT4  57
           CALL SETCLR('BLACK')                                   DAT4  58
           XSIZE=9.0                                              DAT4  59
           YSIZE=6.0                                              DAT4  60
           CALL AREA2D(XSIZE,YSIZE)                               DAT4  61
C                                                                 DAT4  62
C          PLOT TITLE                                             DAT4  63
C                                                                 DAT4  64
           CALL HEIGHT(.25)                                       DAT4  65
           CALL HEADIN(TITLE,32,1.1,1)                            DAT4  66
           CALL GRAF(XORIG,XSTP,XMAX,YORIG,YSTP,YMAX)             DAT4  67
           IMARK=0                                                DAT4  68
           IF(ICOLOR.EQ.1)CALL SETCLR('BLUE')                     DAT4  69
C                                                                 DAT4  70
C          PLOT DATA                                              DAT4  71
C                                                                 DAT4  72
60         CALL CURVE(X,Y1,NPT,IMARK)                             DAT4  73
           IF(IMAXC.EQ.IEP) CALL ENDPL(JJ)                        DAT4  74
           RETURN                                                 DAT4  75
1000       FORMAT(6E10.3)                                         DAT4  76
2000       FORMAT(' PLOT SCALES - ',6E13.5)                       DAT4  77
3000       FORMAT(' PLOT LIMITS - ',2I5,2F10.4)                   DAT4  78
           END                                                    DAT4  79
C
           SUBROUTINE MATMPY (A,B,C,I,J,K,L,M,N)                  MATMPY   1
C                                                                 MATMPY   2
C          A(I,J) B(J,K) ARE ACTUAL DIMENSIONS WITHIN             MATMPY   3
C          MAX DIMENSIONS OF A(L,) B(M,) C(N,)                    MATMPY   4
C          REST OF RESULT C IS NOT SET TO ZERO                    MATMPY   5
C                                                                 MATMPY   6
           DIMENSION A(L,J),B(M,K),C(N,K)                         MATMPY   7
           DO 2 I2=1,K                                            MATMPY   8
           DO 2 I1=1,I                                            MATMPY   9
           C(I1,I2)=0.                                            MATMPY  10
           DO 2 I3=1,J                                            MATMPY  11
2          C(I1,I2)=C(I1,I2)+A(I1,13)*B(I3,I2)                    MATMPY  12
           RETURN                                                 MATMPY  13
           END                                                    MATMPY  14
```

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